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Evaluating Simulators in FIRST Robotics Competition

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Evaluating Simulators in FRC

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Abstract

This report, in completion of the Inquiry Seminar Project and prepared for For Inspiration and Recognition of Science and Technology (*FIRST*), Defense Advanced Research Projects Agency (DARPA), and Open Source Robotics Foundation (OSRF), examines simulators used within the *FIRST* Robotics Competition (FRC) in order to assess the usefulness of simulation tools amongst FRC teams. This is done through researching previous simulators used, and gaining survey data from FRC teams on a new simulator using Gazebo. Data gained through competition demonstrations and a beta of the FRC Gazebo plugin is used to assess the future of Gazebo and simulators in general amongst FIRST.

Executive Summary

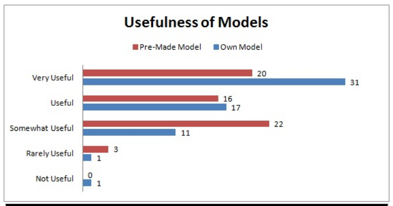
Testing is a necessary, but often expensive step in the engineering process. Prototyping preliminary designs costs time and capital that could otherwise be allocated to production and validation of the final model. Computer simulation reduces the cost of prototyping by enabling developers to test electronic models in a virtual environment, thereby cutting out the time and expenses associated with physical prototyping and testing. Recognizing these advantages of simulation tools, the Defense Advanced Research Projects Agency (DARPA) is supporting the development of Gazebo, an open-source robot simulation tool developed by the Open Source Robotics Foundation (OSRF). DARPA used Gazebo in the virtual trials for the 2013 DARPA Robotics Challenge (DRC) in order to evaluate software written by entrants in the competition. Recognizing Gazebo's potential utility as an industry standard, DARPA is now looking to For Inspiration and Recognition of Science and Technology (FIRST) Robotics as a venue to introduce Gazebo to students who are likely to pursue careers in robotics engineering.

FIRST Robotics aims to inspire students in grades K-12 to pursue careers in Science, Technology, Engineering and Math (STEM) by exposing them to the engineering process. FIRST Robotics Competition (FRC), the high school division of FIRST, challenges students to work alongside engineering mentors to design, build, program and test a robot to play a game in six weeks.[1] One challenge FRC teams face is that there is often not enough time to test and develop software because much of the build season is consumed by prototyping and building hardware. Additionally, it is rare for teams to build a full-scale prototype for testing once the finished robot has been shipped to competition, or "bagged." Individual teams are largely responsible for acquiring resources to build their robots outside of the kit of parts FIRST provides, which is no easy task.

Theoretically, simulation provides a solution to these time and financial constraints that limit teams' ability to test their designs. However, it is first important to evaluate whether FRC teams would realistically use these tools. In order to evaluate the desire and need for simulators in FIRST, this investigation was conducted to assess Gazebo's future potential, and simulators like it. A six man team of students at Worcester Polytechnic Institute (WPI) created a plugin to Gazebo in order for teams to write Java code for FRC and apply it to a simulated robot. Documentation for installing Gazebo and importing either pre-made or custom made robots were

[1] *FIRST* Robotics n.d.

created. In collecting data for assessment, two methods were used. First, a group of interested FRC teams volunteered to beta test Gazebo and gave feedback during certain points of the build and competition season. Second, demonstrations were set up at at competitions and showcased to competing teams, after which teams could fill out a survey on their opinion of the simulator and what they wished to see in simulation.



	Mean	Standard Deviation
Own Model	4.25	0.84
Pre-Made Model	3.87	0.87

Figure 1: Graph and Statistics on Usefulness of Models

During the demonstrations at the competitions, overall 67% noted that they prefer to use a custom made robot model than a pre-made robot model, indicating the desire of FRC teams to simulate their own robots to test on.

The usefulness of custom to pre-made models was ranked on a scale of one to five, as Figure 1 shows along with the mean and standard deviation. As you can see, teams definitely find using their own models more useful than pre-made models. It is important to note however, that pre-made models still score highly between "Somewhat Useful" and "Useful" on the scale, which would indicate that some teams still find pre-made models useful, mostly those that do not use CAD software like SolidWorks, or those that see the simulator as a learning tool for new programmers.

At the competitions, teams were also asked to rank various pre-determined features Gazebo could offer. These features included overall simulation of competition modes such as teleoperated and autonomous to more specific testing of mechanical system, robot protypes, and sensors. These were ranked once again on a usefulness scale as Figure 2 shows. The mean and standard deviation are also listed for each feature in Table 1. Features are ranked by their highest mean, with the standard deviation as the tie breaker.

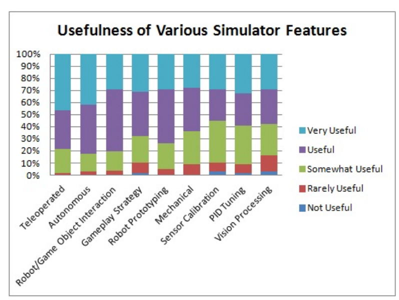


Figure 2: Graph on Usefulness of Various Simulator Features

Both Teleoperated and Autonomous features ranked highest mean amongst the 36 FRC teams that responded to the New England district event surveys. Developing Gameplay Strategy also ranked highly, and had the lowest standard deviation, indicating the greatest consensus amongst teams on the usefulness of developing strategy through the simulator. Lowest ranked features, by mean, included PID Tuning and Vision Processing, showing the less interest in hardware tuning, but are not ranked so low that teams find them rarely useful or not useful at all.

Gazebo Feature	**Mean**	**Standard Deviation**
Teleoperated	4.23	0.75
Autonomous	4.22	0.65
Game Manip.	4.07	0.61
Strategy	4.03	0.55
Prototyping	3.92	0.70
Mech. Testing	3.83	0.64
Sensor Calib.	3.83	0.66
PID Tuning	3.75	0.73
Vision Process	3.68	0.60

Table 1: Statistics of Gazebo Features

The beta initially had thirteen beta participants which increased after demonstrating the simulator at multiple competitions. During the beta, teams were given the documentation to install Gazebo, as well as the robot models and sample code to test with Gazebo. Responses from surveys were very light however. This may be due to the documentation and required beta materials being released late, during the middle of build season, where teams are the most busy.

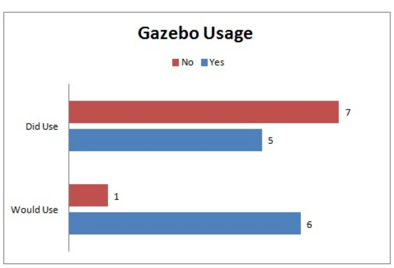


Figure 3: Graph on Gazebo Usage

Figure 3 is data received from beta respondents throughout the beta, with majority of beta users not having used Gazebo. Those that did use the simulator ranked it mostly positively, though remarking on issues of complexity between the documentation and installation process. Gazebo still has a good connection with FRC, as majority of beta teams would still desire to try and use Gazebo again in the future, albeit with some improvements.

The results from the preliminary beta test and FRC event demonstrations enabled this IQP team to make several recommendations for improving the simulator to the development team. First, the installation process for Gazebo should be as simple as possible and streamlined. The SolidWorks URDF export tool for custom robot models needs to be greatly improved upon.

Currently it takes two students with seven years of FRC experience each about eight hours to import a CAD model of a 2014 FRC robot into Gazebo successfully, without functionality with WPILib. Simplifying this process will give it a significant advantage over other simulators in FRC. Additional compatibility needed would include additional language implementation such as C++ to reach more teams.

The results of this study also revealed ways that Gazebo should be released and marketed to teams to enable them to use it successfully. Respondents recommended that the entire simulator be available in the Fall in order to allow users enough time to install and familiarize themselves with it before using it as a tool during build season. Anecdotal evidence also suggests that teams' leadership saw value in Gazebo's use as an educational tool. This is because teams often have more students than can actively work on code at any given time, so writing software for pre-designed robots provides a low-risk and low-cost testing environment for new programmers. These marketing and technical recommendations will enable future releases of Gazebo to be more successful.

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1 Introduction

Testing is a necessary, but often expensive step in the engineering process. Prototyping preliminary designs costs time and capital that could otherwise be allocated to production and validation of the final model. Simulation reduces the cost of prototyping by enabling developers to test models created with computer-aided design tools in a virtual environment, thereby cutting out the time and expenses associated with physical prototyping and testing. Professor Stefan Thomke of MIT's Sloan School of Management illustrates the advantage of simulation in testing by comparing physical and virtual testbeds for car crashes. Thomke writes:

> *"Studying automobile structures via real car crashes... can cost in excess of one million dollars and may take up a year to build and test. In contrast, once the proper digital models have been created, a virtual car crash can be run again and again within a computer under varying conditions at very little additional cost per run.*[2]

Thomke highlights the major advantage of simulation: it enables developers to quickly run multiple tests that would otherwise take significant time and capital to reproduce. Simulation tools therefore make opportunities for innovation more accessible to developers that do not have the capital required to validate preliminary designs with physical prototypes.

1.1 Simulation in For Inspiration and Recognition of Science and Technology (*FIRST*)

Recognizing the advantages of simulation tools, the Defense Advanced Research Projects Agency (DARPA) is supporting the development of Gazebo, an open-source robot simulation tool. "DARPA hopes the creation of a widely available, validated, affordable, and community supported and enhanced virtual test environment will play a catalytic role in development of robotics technology..."[3]. DARPA used Gazebo in the virtual trials for the 2013 DARPA Robotics Challenge (DRC) in order to assess controls software written by teams interested in competing but lacking the capital to build their own robot from scratch. After recognizing Gazebo's potential as a candidate to fill the need for virtual test environment, DARPA is now looking to FIRST Robotics as a venue to introduce Gazebo to students who are likely to pursue

[2] Thomke, Hippel and Franke 1997, 9
[3] DARPA n.d.

careers in robotics engineering.

FIRST Robotics aims to inspire students in grades K-12 to pursue careers in Science, Technology, Engineering and Math (STEM) by exposing them to the engineering process. FIRST Robotics Competition (FRC), the high school division of FIRST, challenges students to work alongside engineering mentors to design, build, program and test a robot to play a game in six weeks. At the end of the six-week "build season," teams are required to stop working on their robots until competition.[4] One challenge FRC teams face is that there is often not enough time to test and develop software because much of the build season is consumed by prototyping and building hardware. Additionally, it is rare for teams to build a full-scale prototype for testing once the finished robot has been shipped to competition, or "bagged." Individual teams are largely responsible for acquiring resources to build their robots outside of the kit of parts FIRST provides. It is difficult for FIRST teams to acquire enough resources to build more than one robot.

1.2 Project Goals

The purpose of this Interactive Qualifying Project (IQP) was to evaluate the effectiveness of simulators in FRC by reviewing previous simulation efforts and supporting the testing of Gazebo with a select group of beta teams.

The first part of the project entailed evaluating the effectiveness of simulators in FIRST. This was addressed by reviewing the results of previous work related to simulators in FIRST, and identifying where additional information is needed. A summary of this previous work is provided in the Background section of this report. Once analysis of past simulators was complete, more directed surveys were designed and issued to teams to gather missing information.

The second part of the project involved supporting the beta of DARPA's Gazebo simulator for the 2014 build season. In order to prepare for the beta, the IQP team created support documentation with the aid of the FRC Gazebo development team. Deliverables include tutorials on installation, exporting models from SolidWorks, importing models into Gazebo, and troubleshooting. During build season, the IQP team reached out to the beta teams on roughly a weekly basis to evaluate their progress with the simulator. Feedback from these communications was used to improve the support documentation.

[4] FIRST Robotics n.d.

This final report uses the feedback gathered from beta testing teams and samples of teams from the New England area to make recommendations on how Gazebo can be improved in terms of functionality and usability. This report also addresses how FIRST can support and promote the use of simulators.

The ultimate goal of these recommendations is making Gazebo a tool that FIRST teams will use to improve both their success in competition and the experience for students.

2 Background

The following section provides the context for this IQP. It introduces all of the parties involved in the development and distribution of the FRC (*FIRST* Robotics Competition) Gazebo plugin, provides a description of the plugin, and discusses simulators that have been previously used in *FIRST* as well as surveying and research techniques that will be considered for the project methodology

2.1 Open Source Robotics Foundation (OSRF)

OSRF develops the two primary tools used for the technical development of the FRC Gazebo Simulator. The first is Gazebo itself, and the second is Robot Operating System (ROS), open source software designed to simplify development for robotics applications.[5] Over the course of this project, the IQP team met with a representative from OSRF on a biweekly basis via telephone conference to receive updates on Gazebo development. In turn, the IQP team provided feedback from Gazebo users on FRC teams, as well as informal recommendations on how to improve the simulator. In the summer of 2014, a student from WPI will be working with OSRF to improve Gazebo. Part of the purpose of this project is to provide development recommendations to this student, which are summarized in Chapter 5 of this report.

2.2 Defence Advanced Research Projects Agency (DARPA)

DARPA is an agency of the United States Department of Defense that funds technical research projects.[6] DARPA supports development for Gazebo, and hopes that it will become an industry standard virtual testbed. Because *FIRST* Robotics alumni often pursue careers in or related to

[5]ROS n.d.
[6]DARPA n.d.

robotics engineering, DARPA recommended making Gazebo available as a tool to high school students involved in *FIRST*. This way, students would be familiar with the software before entering the industry, and thus be more likely to use it later.

2.3 For Inspiration and Recognition of Science and Technology (*FIRST*) Robotics

FIRST Robotics is a non-profit organization aimed at "[transforming] our culture by creating a world where science and technology are celebrated." To do this, *FIRST* engages students in annual robotic competitions in several different divisions. The target division for this project is FRC (*FIRST* Robotics Competition). FRC challenges high school students to work alongside engineering mentors from sponsoring industries to design, build, program and test a robot to play a game with robots built by other teams. A major constraint of FRC is that teams only have six weeks from the moment they learn about the game to build and test their robot. This is commonly referred to as the "build season", and for the 2014 FRC Gazebo beta, build season began on 4 January 2014 and ended 18 February 2014. Because of the time constraint, teams often have little time for testing because most time is spent designing and building the robot. The hope is that improving simulation tools with provide teams with a way to extend their testing process outside of the six weeks they are allotted to work on their physical robots.

2.3.1 *FIRST* Robotics' Scope and Impact

FIRST asked Brandeis University's Center for Youth and Communities to assess the impact of FRC on students during the 2010 and 2011 seasons. Of the 710 students who responded to the 2011 Brandeis study, 80 percent or more reported that as a result of *FIRST*, they were more interested in science and technology careers, performing well in school, and attending college.[7] *FIRST* also impacts a large number of students globally; approximately 71,250 students from 2,850 teams from around the world will compete in the 2014 FRC season.[8]

Based on the positive correlation between student participation in *FIRST* and interest in careers in STEM, DARPA has targeted FRC as a venue to introduce future robotics engineers to Gazebo—a tool that DARPA hopes will become industry standard.

[7] Brandeis University 2011
[8] *FIRST* Robotics Competition 2013)

2.4 *FIRST* Robotics Competition (FRC) Gazebo Plugin

The FRC Gazebo plugin was developed and supported by four WPI graduate students and two WPI undergraduate students. The plugin uses ROS to provide an interface which will allow FRC teams to control their simulated robots with WPILib programs similar to those for their physical counterparts. WPILib is a collection of C++, LabVIEW and Java libraries that FRC teams use to create robot programs. The initial version of the plugin only supports teams that write software in Java. According to data collected by National Instruments, this represents roughly 30% of teams.[9] Ideally, there will not be a difference between simulated robot code and real robot code. In addition to writing custom software for pre-built robots, teams will eventually be able to export their own CAD models from SolidWorks to Unified Robot Description Format (URDF) files. URDFs are Extensible Markup Language (XML) files that represent robot models created in SolidWorks, and can be imported into Gazebo for simulation.

2.5 Goals for the 2014 Season Gazebo Beta

The goal of the 2014 Season Gazebo Beta was for teams to be able to import three pre-made and provided robot models and test their own software on these models. Providing pre-made robot models meant teams would be able to practice writing robot code, but it did not allow them to test code on their own designs. Under ideal circumstances, teams that want to import their own models into Gazebo to test code and practice driving and operating mechanisms would be capable of doing so by the end of this trial. While this was by no means guaranteed or critical to the success of this IQP, it is the ultimate goal for the FRC Gazebo simulator in the long-term

2.6 Previous Simulation Research

Other IQP groups have previously investigated the feasibility of two different simulators: 5^{th} Gear and LabVIEW. The following two sections briefly describe the methodology and results of these previous investigations, and the gaps they leave for research with Gazebo

2.6.1 5^{th} Gear

The most well-defined and tested simulator that has been implemented in *FIRST* Robotics is a tool called 5^{th} Gear, which was developed by engineers from Lockheed Martin who also serve

[9] Henning, McLeod and Silberberg 2013, 33

as mentors on *FIRST* teams. 5^{th} Gear supports up to six players and enables them to choose from three distinct robots that fill different roles (e.g. scoring, defensive play, etc.). Players select and operate their robot during a two-minute match modeled after FRC games from 2008 and 2009. An advantage of 5^{th} Gear over Gazebo is that it is an independent package that does not require teams to program or model robots. However, this also means it cannot be used for software development and testing during build season.

5^{th} Gear differs from Gazebo in that its goal was to provide an entertaining experience to students while enabling them to simulate how the game would play out before taking their physical robots to the field. By contrast, Gazebo is a technical tool for software development and simulated hardware testing.

An IQP analyzing teams' reception of 5^{th} Gear was conducted in 2009. The group traveled to multiple *FIRST* competitions and set up demonstrations of 5^{th} Gear for FRC students and mentors to try. Multiple end users commented that they wanted to be able to customize their robot in the simulator, which is a feature that Gazebo provides.[10]

Gazebo fulfills different roles than 5^{th} Gear, as described above. Additionally, Gazebo is currently in an earlier phase of development than 5^{th} Gear was at the time of the 2009 IQP. For these reasons, the FRC Gazebo beta methodology is more focused on following a smaller sample of teams over the course of the build season.

2.6.2 LabVIEW Simulator

Another IQP team has already examined the use of simulators designed for assisting in software development. As a part of their IQP, they evaluated the reception of the LabVIEW Simulator, which was included in the 2013 kit of parts. According to their research, there is some promise for simulation in *FIRST*. While a simulator must meet a few criteria to be viable, most teams who answered their survey showed some interest. Many test subjects stated that the simulator was too difficult to use. Out of 127 responses to another survey, 75% said they might use the simulator if they could import their own robot.[11] This is a feature Gazebo will eventually provide, which means researching and improving Gazebo is a valuable task improve FRC teams' tools and experience.

One issue with the LabVIEW Simulator was that many teams do not use LabVIEW to write

[10] Dutra, et al. 2009
[11] Henning, McLeod and Silberberg 2013, 134

their robot control programs. While many teams expressed interest in simulators, they were not willing to change their primary programming language in order to use one. A simulator that supported programming in Java, C++ and LabVIEW would make teams more likely to use it.

There was only one complaint about the physics in the LabVIEW Simulator, but multiple complaints about the simplicity of the supplied robots. Additionally, several teams mentioned how their computer could not handle the simulator at reasonable speeds, while a few others reported that their computers could not handle it at all. Speeding up the simulation requires either better software, less complex robots, or better hardware. While improving software efficiency is a possibility, at some point, hardware requirements and complexity requirements will clash. This means that teams with better hardware will be able to get more out of the simulator.

3 Methodology

The following section describes the methods used to assess the usability of Gazebo in the FIRST environment. The methods discussed include choosing and soliciting beta teams, distributing Gazebo, and surveys conducted to collect feedback on the software.

3.1 Creating a Beta Environment

In order to facilitate software distribution and communication with the FRC Gazebo beta teams, the IQP team created a space on TeamForge. TeamForge is a cloud-based collaboration platform that FIRST uses to distribute and share source code with teams. Using this platform, teams posted bug reports and other feedback to both discussion boards and "trackers". These trackers directed teams through basic tasks related to using Gazebo, for instance, installing all of the packages and running sample code provided through TeamForge. Samples of each tracker created can be viewed in Appendix A. An email alias (gazeboiqp@wpi.edu) was also distributed for testers to contact the IQP team members directly with questions or concerns. Tutorials for installation and basic programming tasks were created with ScreenSteps, software designed to create and host tutorial documentation. These tutorials were written iteratively over the course of several weeks, and were continuously tested by both the IQP team and the development team before release.

3.1.1 Selecting Build Season Beta Teams

Twenty 2014 Control System beta teams using Java were solicited via email to participate in the first round of the FRC Gazebo Beta. Of these twenty teams, seven expressed interest and joined the TeamForge. Because this number was below our target of 12-15 teams, some additional teams were added to the project via word of mouth. As a result, there were thirteen beta teams at the beginning of the 2014 FRC build season. Each team was instructed to create a TeamForge account and email the "gazeboiqp" alias with their username so the project admins could add them to the project. Read-only ScreenSteps accounts were also created for these users to provide access to ScreenSteps tutorials without releasing the early drafts of documentation to all of FIRST.

These teams were asked to appoint one liaison responsible for communicating with the IQP team and distributing the surveys described in the following sections amongst the FRC Gazebo users on their team.

3.2 Surveys

A total of three surveys were given out to the beta testing teams during the FRC build season: one pre-season, one mid-season, and one post-season. Qualtrics, a research software platform, was used to write and distribute the surveys, and record the results. Subjects were asked to record their team number to help with establishing trends throughout the beta. Because the surveys were semi-anonymous, all data received was password protected and used only for statistical analysis. The raw data pertaining to any identifiable information is only accessible to the IQP team, and the data in the Results section and the raw results in the appendices do not include any identifying information. Target audiences for this analysis include DARPA, FIRST, the graduate development team at WPI, and the IQP team's advisors.

3.2.1 Pre-Season

One survey was distributed before teams received the Gazebo simulator. It was distributed to the initial round of testers and required for each tester who was later added to the project. Each team's liaison filled out this survey, resulting in one survey per beta team for analysis. This survey's goals included assessing teams' background knowledge related to simulation, the types of functionality they desire in a simulator, and the hardware available to them. These data are useful for a number of reasons. First, assessing how much an average team knows about simulation and Ubuntu helped the IQP team tailor support documentation to FIRST teams. Second, knowing what functionality teams desire in a simulator also enables the development team to prioritize new functions based on feedback from the end users. Third, knowing what hardware is available to an average team helps predict issues teams may run into based on hardware requirements.

3.2.2 Status Updates

Around the middle of build season, two methods were used to gauge how much teams had been using Gazebo in parallel with their robot design process. The first method was a status update that asked testers to provide their team number and a short, open-ended summary of their progress so far.

3.2.3 Post-Beta Survey

One survey was distributed partway through competition season and included the original teams that signed up for the beta as well as other teams that expressed interest at the district competitions. This survey was distributed to every individual that signed up for the Gazebo beta. This survey consisted of multiple-choice and additional open-ended questions to gather final feedback and performance overviews from all the teams participating in order to assess either the success or failure of the simulator during the build and competition seasons. Data from this survey also provided information about further improvements teams desire to make Gazebo accessible for all FRC teams. Because of the low response rate when the survey was initially released, we added an incentive to this survey. Individuals that responded to the survey could include their email address to be entered in a raffle for a $50 gift card to Amazon, Newegg or Barnes and Noble. To provide an additional incentive for completing the trackers listed on TeamForge, the IQP team entered additional tickets for individuals who completed tasks using Gazebo. The number of tickets assigned to each task can be seen in Table 2.

As an alternative to completing the Post-Beta survey, we included a short list of basic questions in the email and requested that teams reply to the email and answer the questions. This was intended to target possible respondents who were not interested in the raffle incentive and did not have time or interest in filling out a longer survey. The questionnaire may be seen in

Task	Tickets
Completing the Post-Beta Survey	1
Tracker: Install Linux	1
Tracker: Install Gazebo and Related Programs	1
Tracker: Run GearsBot Sample Code in Gazebo	2
Tracker: Task 1: Behind the Box	2
Tracker: Edit and Test GearsBot Sample Code	2

Table 2: Ticket Values of Beta Tasks

Appendix A. The same questionnaire was also used to interview beta testers in person at the Boston University regional.

3.2.4 District and Regional

A survey was created for each district event that was attended for demonstrations (a list of regionals and information about the demonstrations can be found in Section 3.6). This survey collected information on team backgrounds in logistics, programming, and CAD design as well as assessed their knowledge and/or use of past simulators. Questions also gauged what types of functionality they wished to see in Gazebo, and if they tried out the demo, how they would rate the experience in functionality, usability, and utility. The FRC teams who filled out the survey and marked that they programmed in Java or used SolidWorks for CAD were also asked if they would like to join the beta, and if so, contact information was collected.

The purpose of this survey was twofold. Firstly, it assessed a wider sample size and reaction from the FRC community about what they want to see from a simulation tool, as well as Gazebo's current state. Secondly, the survey collected interested beta testers in order to gain crucial feedback and results for the final assessment of the simulator.

3.3 Data and Analysis

The small sample size of 12-15 beta teams provides advantages and disadvantages for data collection and analysis. Significance of data improves with sample size; because such a small sample size was used for the Gazebo beta, the data will mostly be used for technical development. One advantage of a small sample size is the viability of using open-ended questions for analysis. Open-ended questions may provide "logic or thought processes, the amount of information they possess, and the strength of their opinions or feelings."[12] Each of these qualities will be useful

[12] Royce A. Singleton 2010, 313

for a baseline of feedback for technical development and support documentation. For example, it will be useful to know which features teams use the most and what they would like to see added going forward.

Two major categories of data were gathered in order to assess whether Gazebo is making teams more successful, and what should be added to the functionality or documentation to make its implementation in FRC more successful. The first category is directly related to Gazebo and its performance and features, and the second is related to simulation in general and what features teams want to see. The former category is applicable only to the FRC Gazebo beta teams, while the latter is more general information that may be gathered from a large sample of FRC teams. The data analysis will provide feedback to DARPA, OSRF and the development team in terms of how functionality and usability can be improved. The analysis will also provide suggestions to FIRST for how to market the simulator to teams to increase the number of students being exposed to Gazebo. Marketing of simulators involves how teams are encouraged to use Gazebo. For example, if teams do not have enough time to use Gazebo during build season, the analysis will recommend that FIRST encourages teams to use it after the ship date to refine code for competition. Other potential uses outside of build season include off-season research projects and programming education.

3.4 Support

During the course of this study, participating beta teams had support from the FRC Gazebo development team through TeamForge. A forum was set up on the Gazebo TeamForge for participants to post issues with the software and receive assistance. Technical assistance was provided and assessed by the IQP team and FRC Gazebo development team. Trends in issues and their solutions were noted throughout the course of the beta and will be included in the final analysis and discussion.

3.5 Statistical Significance vs. Qualitative Surveying

FIRST has historically declined to mass-distribute surveys to FRC teams in order to prevent survey fatigue, so alternative data acquisition methods were necessary. A small demographic of teams was selected to participate in the FRC Gazebo beta in order to ensure that the IQP team was able to adequately support each participant. While the success of the IQP did not depend on teams finding Gazebo useful, it was a goal to make teams' experiences with Gazebo as high-quality as possible to reflect future full releases of the plugin. The demographic initially invited to the beta was small, but geographically diverse. After build season ended, we noted that we needed to increase the number of teams participating in the beta due to the low task progress from the original teams. The following strategies were employed to increase the number of teams participating in the beta.

3.6 District Competition Demonstration

The IQP team attended four New England District Competitions to reach out to FRC teams. One goal of the demonstrations was to raise awareness of the FRC Gazebo beta project. Other goals included gathering feedback from visitors who used the simulator, and registering more teams for the beta test. One of the drawbacks of collecting beta participants as part of the surveying process was that teams that did not use Java (and were therefore ineligible for the beta test) were screened out of the surveying process. This reduced the number of respondents from the regional to be closer to the number of teams that use Java, and also narrowed the perspective to be from teams that use Java. This was acceptable however, because this did not affect the data used to support development of Gazebo for compatibility with C++.

3.6.1 Demonstration Concept

The original concept for the demonstration was as follows: participants would be able to edit a sample program and run it on a simulation of GearsBot (a small robot which FRC team 190 uses for their own community outreach), as well as the physical robot at the booth. The demonstration would show that both the actual robot and virtual robot will behave in the same manner. A poster was created to provide background information about the simulator, because the audience at these events had never seen the simulator before. A photo of the poster may be found in Appendix C.1.

The actual demo consisted of GearsBot running in the sandbox world in Gazebo on a virtual Linux machine. The physical GearsBot was at the regional, but its drivebase was configured differently than the model's, which meant that the robot would behave differently from the simulation. Autonomous coding tasks were provided, but visitors only spent enough time to drive GearsBot in teleoperated mode or view the autonomous code due to the ongoing FRC competition. While this does not necessarily mean that teams would prefer to use the simulator for tele-operated drive testing over code testing, it did suggest that this was a more impressive method for demonstration.

The list of FRC competitions attended can be found in Table 3. The installation used for the demonstrations was problematic to set up, and is detailed below. Each demonstration was slightly different, and the differences are discussed in subsections below where applicable.

Competition	Date	Number of FRC Teams
Granite State District	3/1/2014	39
Groton District	3/8/2014	33
WPI District	3/13/2014	40
Rhode Island District	3/21/2014	37
Northeastern District	3/29/2014	40
New England FRC Region Championship	4/10/2014	53

Table 3: Competitions Attended

3.6.2 Demonstration Installation

The machine that was used to demonstrate Gazebo at the regionals contained a modern i7 CPU, 32GB 1866MHz RAM, and an Nvidia GeForce GTX 780 graphics card. Installation was first attempted on a VirtualBox virtual machine running Ubuntu 13.04. While the simulation ran with hardware acceleration off, it ran too slowly and suffered from severe input lag. When hardware acceleration was turned on, Gazebo crashed. A native version of Ubuntu 13.04 hosted the next attempt. The simulation software installed smoothly as expected, but the Nvidia graphics drivers did not. This was a documented bug in 13.04, and since 13.04 had already been abandoned by Canonical (the company that produces Ubuntu), the bug will never be fixed. Several workarounds and alternate driver installation methods were tried, though none to any avail. The next attempt was on a native install of Ubuntu 12.04 Long Term Support (LTS). While both the graphics drivers and simulation software installed, Gazebo did not interact with the NetBeans plugin. The IQP team then tried installing on a native ArchLinux install, and some necessary packages failed to install.

Finally, an installation on Ubuntu 13.10 was attempted. The graphics drivers installed properly, but ROS Hydro was not packaged for 13.10. In order to properly install it, it had to be compiled from source. Once ROS was compiled successfully, the simulation ran at full speed and without any noticeable bugs. Since then, the IQP team has written an installation script located in Appendix D.1, which can be used to install the entire system on Ubuntu 13.10.

3.6.3 Granite State District

After attending the Granite State District Competition, the IQP team met with DARPA and OSRF to review results and acquire suggestions for improving the demonstration and surveys. OSRF expressed interest in gathering information about the typical FRC team's design process in order to assess how useful teams would find a robot modeler integrated into Gazebo. Questions were added to the District Competition Survey and submitted to OSRF for feedback. The revised survey (see Appendix A) was distributed at all FRC competition demos following the Granite State District.

3.6.4 Groton and WPI Districts

These two district competitions were set up similarly to the Granite State District, except the survey distributed to teams was updated with questions of interest to DARPA and OSRF. The IQP team had some difficulty getting FRC teams to fill out the survey because no incentives were provided, and several team members complained about the length of the survey because of the added questions. The feedback the IQP team got from these regionals improved our approach for the final two competitions–Rhode Island and Northeastern.

3.6.5 Rhode Island and Northeastern Regionals

These were the most successful events the IQP team attended for several reasons. There was some difficulty getting teams to fill out the survey at the Granite State, Groton and WPI district competitions, and so the IQP team provided extra incentives to attract FRC team members and mentors to our booth. Participants in the survey were allowed to take their choice of robot-shaped stress balls, puzzle cubes and candy as a reward for filling out the survey. As a result, the number of survey responses from the Rhode Island event more than quadrupled the average response counts from previous events, despite it having fewer teams present than either the WPI or Granite State districts. No survey data was collected from the Northeastern district, because by that time sufficient data had been collected that showed teams were interested in the simulator. Instead, more users were registered for the beta by having them sign up for TeamForge on a laptop present at the display.

3.6.6 Boston University District Championship

The goal of attending the Boston University District Championship event was to collect feedback from teams that had signed up at previous district competitions but had not responded to any of the online surveys. Participants from five present teams were interviewed using questions from the Post-Beta questionnaire (see Appendix A.6). Four of these completed the questionnaire, and the fifth declined because they had not had time to use the simulator at all.

4 Results

The following chapter details the results obtained throughout the course of the project, which include feedback from surveys and issues and comments addressed by teams through TeamForge. The results address feedback from two perspectives of the FRC Gazebo Simulator: its theory and practice.

4.1 Survey Data on Theory

This section discusses what FRC students and teams think of the concept of the FRC Gazebo Simulator, and generally how prepared they would be to successfully use it. These points are addressed by results obtained at four different regional competitions, each having its own subsection to discuss the differences in results. The fifth and last subsection will be an accumulation of all regional results for a full scale analysis of the theory of use for the FRC Gazebo Simulator.

The following questions in Table 4 were posed at each regional with the parameters which respondents could answer. The only exception is the Granite State Regional, which was not asked questions on Custom vs. Pre-Made Models, Model Integration, and Design Process Characterization. Each event has its own subsection for commentary and statistics of the individual results, with a final overall review in Section 4.1.5.

Question Being Asked	**Parameteres of Responses**
Linux Experience	Each respondent was asked to rate their Linux experience on a 1 to 5 scale from "No Experience" to "Expert" respectively.
Custom vs. Pre-Made Models	Each respondent was asked to rate the usefulness of testing on a Pre-Made or Own Custom made model on a scale of 1 to 5, with 1 being "Not Useful" and 5 being "Very Useful".
Model Integration	Respondents were asked if they preferred to create a robot in a CAD software to import into Gazebo, or to create the robot model within Gazebo itself.
Design Process Characterization	Respondents were asked if they develop a detailed design and attempt to build once and test, if they quickly develop a design to iteratively build, test, and redesign, or if they Prototype rough sketches immediately which are modified based on extensive testing until a final design is reached.
Desired Simulation Functions	Respondents were asked to rate various features of Gazebo on a scale of 1 to 5 with 1 being "Not Useful" and 5 being "Very Useful".
Gazebo Demonstration Feedback	Respondents that ran Gazebo at the demonstrations were asked to rate its Functionality, Usability, and Utility on a scale from 1 to 10, with one being very poor and 10 being very high.
Summary	Respondents were asked during what period of the FRC season would they use Gazebo most often: Build, Competition, or Off Season. Last comments about the results are also made.

Table 4: Questions posed at district and regional events

4.1.1 Granite State District Survey Results

The survey conducted at the Granite State District event varied slightly from the surveys conducted at all other district competition demonstrations because it occurred before a feedback session with DARPA and OSRF. The changes made after the Granite State District event added questions about design process and whether they preferred stand-alone CAD software or a 3-D design plugin in Gazebo. While results for those questions are not available from this event, the rest of the questions are valid for comparison with the rest of the district event demonstrations.

There were a total of eight respondents recorded at the Granite State District, shown by Table 5. Each respondent gave general background information on what they did with respect to their team, what type of programming and CAD software their team uses, and if they have ever used a simulator in the past. These results can be seen in Table 6.

Student	**Mentor**
7	1

Table 5: Granite State - Respondents

Position on their FRC Team				
Programmer	**Electrician**	**Mechanic**	**Designer**	**Other**
4	0	2	1	1

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
3	1	1	2	0

Simulators Used in the Past			
None	**5^{th} Gear**	**LabVIEW Sim**	**Other**
5	0	1	2

Programming Language Used			
Java	**C++**	**LabVIEW**	**Other**
7	0	1	0

Table 6: Granite State - General Background Information

The majority of responses were from student programmers,because once visitors realized that Gazebo primarily focuses on software testing, they left to find their teams' programmers, who they felt would be more capable of understanding the tool. A majority of respondents surveyed listed Java as their primary language over C++ and LabVIEW. This is likely because the teams that used the supported language of the beta were most interested in it, which skewed these results. A majority of respondents had not used a simulator in the past. A majority of respondents also do not use CAD software to design their robots, indicating that they would have no custom robots to implement into Gazebo and would have to use pre-made models if they were to use the simulator.

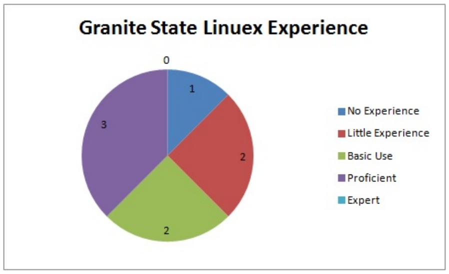

Figure 4: Granite - Linux Experience

Linux Experience

The responses are shown in Figure 4, with a mean of 2.88 and standard deviation (SD) of 1.13. The low average, between "Little Experience" to "Basic Use" suggests that tutorials in the installation and use of Linux are required if teams are to have a positive experience. It would also suggest the need to simplify all documentation and installation methods.

Desired Simulation Functions

The results from Granite State can be seen in Figure 5. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 7.

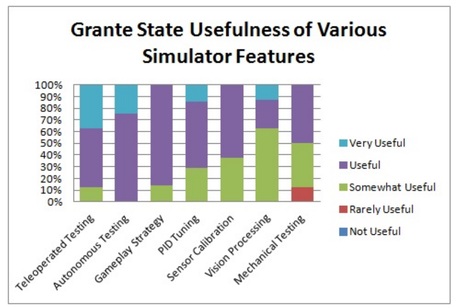

Figure 5: Granite State - Usefulness of Various Simulator Features

It is important to note that at this event, the respondents of this survey were not originally required to rate all of the functions, and so one person did not rate the usefulness of PID tuning or gameplay strategy, but this could not change which simulator function was rated most useful.

Respondents ranked autonomous and teleoperated testing most useful. Standard deviations for these results were low for both applications, but teleoperated testing had a lower SD of 0.46 to autonomous testing at 0.71, signifying a greater consensus about the usefulness of teleoperated testing over that of autonomous testing. The lowest-ranked feature was mechanical testing, with a mean of 3.38, but second highest SD at 0.74. This would suggest that these teams find simulations that mimic FRC competition play more useful than individual compo-

Gazebo Feature	**Mean**	**Standard Deviation**
Teleoperated	4.25	0.46
Autonomous	4.25	0.71
Strategy	3.86	0.38
PID Tuning	3.86	0.69
Sensor Calib.	3.63	0.52
Vision Process	3.50	0.76
Mech. Testing	3.38	0.74

Table 7: Granite - Gazebo Features

nent testing; however, the mean scores are still above "Somewhat Useful", indicating that some teams may still have use for such features.

Gazebo	Mean	SD
Functionality	6.75	1.63
Usability	7.25	0.97
Utility	8.50	1.32

Table 8: Granite - Gazebo Demo Feedback Statistics

Gazebo Demonstration Feedback

All those that took the survey also ran Gazebo at the demonstration. The statistics from those responses can be seen in Table 8. The functionality of the simulator was ranked poorly, with a mean of 6.75. This may be due to the slow framerate of the simulator at the Granite State District, as the computer's Graphics Processing Unit (GPU) was not being utilized and would have solved latency issues. Utility was ranked high at an 8.50 mean, and usability ranked in between at 7.25 with the lowest SD of 0.97. All respondents said that they would use the simulator if made available to them.

Granite State Summary

In asking about when the simulators would be most used, the majority responded that they would use it during build season, as Figure 6 shows. Asked what they would use it for, a majority of responses involved testing code as the actual robot was being built or had been bagged and shipped to competition. Other responses included seeing additional functionality for the robot to perform and to help devise strategies in gameplay and defence.

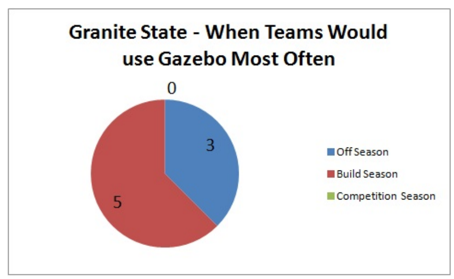

Figure 6: Granite - Gazebo Used Most

While a majority of respondents ranked the functionality of Gazebo low, and many do not use CAD Software indicating that use of custom made robots would not be applicable to most of these respondents, it still received great acclaim and all respondents noted they would try and use the simulator if made available to them. Key features they most desired are those that mimic an FRC competition, such as teleoperated and autonomous modes, with less emphasis on specific type testing such as mechanical components or vision processing. Exact results and statistics from this survey can be seen in Appendix A.7.

4.1.2 Groton District Survey Results

There were a total of 10 respondents recorded at the Groton District, but only 9 completed the survey; their results are shown in Table 9. The partial response was omitted from the analysis. Each respondent gave general background on what they did with respect to their team, what type of programming and CAD software their team uses, and if they have ever used a simulator in the past. These results are seen in Table 10.

Student	**Mentor**
5	4

Table 9: Groton - Respondents

Position on their FRC Team				
Programmer	**Electrician**	**Mechanic**	**Designer**	**Other**
5	2	1	0	1

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
2	4	4	2	0

Simulators Used in the Past			
None	**5^{th} Gear**	**LabVIEW Sim**	**Other**
8	0	1	0

Programming Language Used			
Java	**C++**	**LabVIEW**	**Other**
5	1	2	1

Table 10: Groton - General Background Information

A small majority of responses were from students, who were mostly programmers. In listing what type of CAD software their team uses, unlike the Granite State event, most teams did use some type of software. There was no single dominant program, but SolidWorks and Autodesk Inventor were used the most. This would show that teams have the tools to design a custom robot that could be imported into Gazebo for testing. Most respondents had not used a simulator in the past. In asking what programming language is used, most respondents listed Java, like at Granite State; however in contrast, there were more C++ and LabVIEW programmers that responded as well.

Linux Experience

Responses are shown in Figure 7, with a mean of 3.00 and standard deviation (SD) of 1.73. The mean falling exactly on "Basic Use" suggests that teams have standard knowledge of Linux, but may not be able to easily go through complex steps and process. The high SD however would would suggest the need to simplify all documentation and installation methods and give available tutorials as there is not enough of a consensus to classify the majority of teams as previous Linux users, but rather a split between those that know Linux well and those that do not.

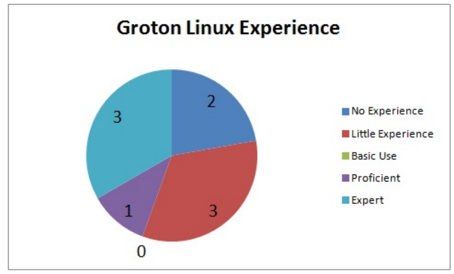

Figure 7: Groton - Linux Experience

Custom vs. Pre-Made Models

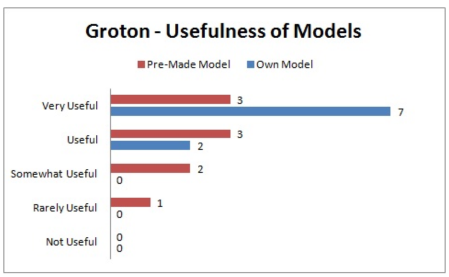

Figure 8: Groton - Model Usefulness

There was a notable preference for importing their own models as Figure 8 shows. On a rating scale of 1 to 5, with 1 being "Not Useful" and 5 being "Very Useful", the mean scores were 4.78 and 3.89, respectively. It is also important to note that the standard deviations for each were 0.44 and 1.05, meaning that there was a greater consensus amongst the respondents on the usefulness of being able to import their own models versus using pre-made models. This supports priority in developing and documenting the ability to import teams' own robot models into Gazebo; however, no one found pre-made robot models to be "Not Useful".

Modeling Integration

A majority of respondents chose to first develop a robot in CAD, and then export it into Gazebo for testing as is shown in Figure 9. However, this data alone is too close to significantly say which method overall teams would support, but there is slight support for designing their robots within a known CAD software to export from than creating it within Gazebo through a plugin.

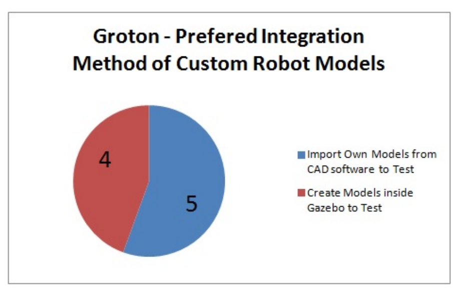

Figure 9: Groton - Integration Method

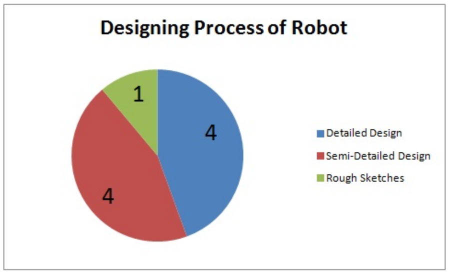

Figure 10: Groton - Design Process

Design Process Characterization

Responses were split evenly between developing a detailed design first, to attempt to build once and test, and quickly developing a design that then gets iteratively built, tested, and redesigned (shown in Figure 10). Only one respondent said their team starts by prototyping rough sketches, immediately followed by modifications based on extensive testing until the final design is reached. This supports the notion that teams spend time designing basic to detailed models of their robots before going into the building, testing, and programming process.

Desired Simulation Functions

Responses can be seen in Figure 11. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 11.

Respondents ranked teleoperated and autonomous testing most useful with mean scores of 4.78 and 4.67, respectively. Standard deviations for these results were low, with teleoperated testing having a lower SD of 0.44 than autonomous testing at 0.50, signifying a greater consensus about the usefulness of teleoperated testing over that of autonomous testing. The lowest ranked features were Mechanical Testing and Sensor Calibration, with means of 3.67 each, and standard deviations of 1.12 and 1.41. An additional feature that one respondent noted would be useful is a repository for community model components, such as gearbox-motor combinations, for use between teams during testing of their robots and systems.

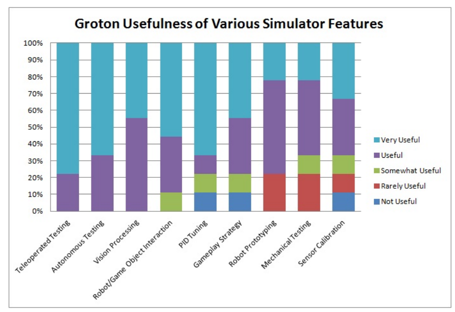

Figure 11: Groton - Usefulness of Various Simulator Features

Gazebo Feature	Mean	SD
Teleoperated	4.78	0.44
Autonomous	4.67	0.50
Vision Process	4.44	0.53
GameObj. Manip.	4.44	0.73
PID Tuning	4.22	1.39
Strategy	4.00	1.32
Protoryping	3.78	1.09
Mech. Testing	3.67	1.12
Sensor Calib.	3.67	1.41

Table 11: Groton - Gazebo Features

Gazebo	Mean	SD
Functionality	9.20	0.75
Usability	8.00	1.67
Utility	9.00	0.89

Table 12: Groton - Gazebo Demo Feedback Statistics

Gazebo Demonstration Feedback

Of those that took the survey, 56% ran the simulator; only respondents that ran the simulator were asked to rank its utility. The statistics from those responses can be seen in Table 12. Based on this, respondents found the simulator to be very useful. Its usability, which still had a high mean at 8, was rated the lowest of the three, and had the highest SD revealing a divide amongst the respondents. This low mean and high SD may be due to the split in Linux experience found earlier by users, and those that are familiar with the type of setting Gazebo is in versus those that are not. Despite this, all respondents responded that they would use the simulator if made available to them.

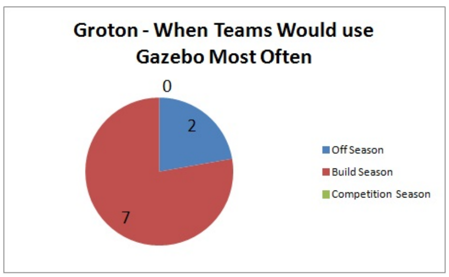

Figure 12: Groton - When Teams Would use Gazebo Most Often

Groton Summary

Most teams would use the simulator during build season for testing code while the robot was being built, as Figure 12 shows. One respondent noted it would be used for training members on the team such as drivers, programmers, designers, etc. and even for use within the classroom for robotic instruction.

The results of this demonstration suggest that potential Gazebo users are excited about this simulator, as all respondents noted they would try and use the simulator if made available to them. Key features they most desired are those that mimic an FRC competition, such as teleoperated and autonomous modes, with less emphasis on specific type testing such as mechanical components or sensor calibration. Exact results and statistics from this survey can be seen in Appendix A.7.

4.1.3 WPI District Survey Results

There were a total of 12 respondents recorded at the WPI District and are shown by Table 13. Each respondent gave general background on what they did in respect to their team, what type of programming and CAD software their team uses, and if they have ever used a simulator in the past. These results are seen in Table 14.

Student	**Mentor**
5	7

Table 13: WPI - Respondents

Position on their FRC Team				
Programmer	**Electrician**	**Mechanic**	**Designer**	**Other**
8	1	1	0	2

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
1	9	4	0	0

Simulators Used in the Past			
None	5^{th} **Gear**	**LabVIEW Sim**	**Other**
10	0	2	0

Programming Language Used			
Java	**C++**	**LabVIEW**	**Other**
10	3	2	1

Table 14: WPI - General Background Information

The majority of responses were from mentors, which is in contrast to the respondents from Granite State and Groton who were mostly students. Most of these mentors were (once again) programmers. In listing what type of CAD software their team uses, the majority of teams did use some type of software, with SolidWorks as the dominant CAD software at this event. This would show that teams have the tools to design a custom robot that could be imported into Gazebo for testing. A majority of respondents had not used a simulator in the past. In asking what programming language is used, most respondents listed Java with a small minority of C++ and LabVIEW programmers that responded as well.

Linux Experience

The responses are shown in Figure 13, with a mean of 2.83 and standard deviation (SD) of 1.40. The average between "Little Experience" and "Basic Use" suggests that teams have little to some knowledge of Linux, indicating teams may not be able to easily go through complex steps and processes easily. The high SD would also suggest the need to simplify all documentation and installation methods and give available tutorials as there is not enough of a consensus to classify the majority of teams as users of Linux.

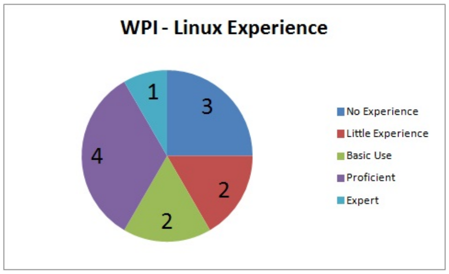

Figure 13: WPI - Linux Experience

Custom vs. Pre-Made Models

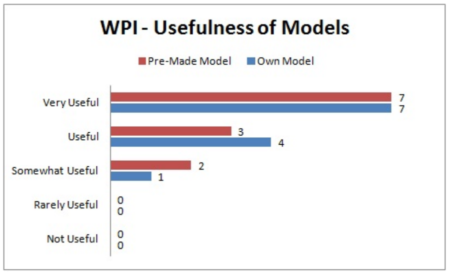

Figure 14: WPI - Usefulness of Models

There was no significant difference between the two modes as Figure 14 shows. On a rating scale of 1 to 5, with 1 being "Not Useful" and 5 being "Very Useful", the mean scores were 4.50 to 4.42, respectively. It is also important to note that the standard deviations for each were 0.67 and 0.79. This means that there was a very slight preference towards importing teams' own models into Gazebo, but because both means and standard deviations are so close, these data alone cannot indicate which is truly considered more important. Rather, it indicates that both teams find both types of models useful.

Design Process Characterization

Even though both custom and pre-made models ranked nearly equal on usefulness, when asked how they would like to integrate a design into the Gazebo simulator, a great majority chose to first develop a robot in CAD, and then export it into Gazebo for testing (as is shown in Figure 15). These data support the notion that teams would rather design their robots within a known CAD program to export into Gazebo than learn to create it within Gazebo though a plugin.

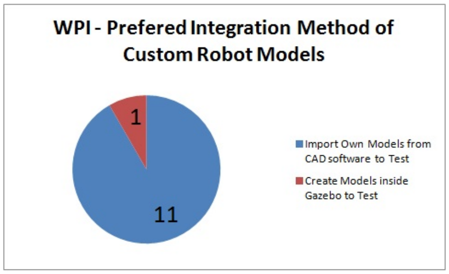

Figure 15: WPI - Integration Method

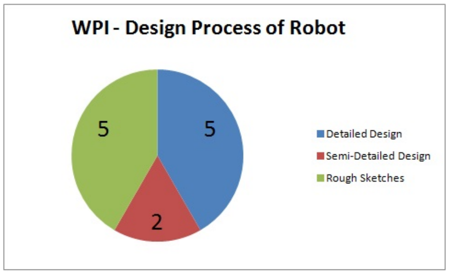

Figure 16: WPI - Design Process

Teams were also asked about their design processes. Responses were split evenly between developing a detailed design first, to attempt to build once and test, and using rapid prototyping until the final design is reached, as shown in Figure 16.

Desired Simulation Functions

Responses can be seen in Figure 17. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 15.

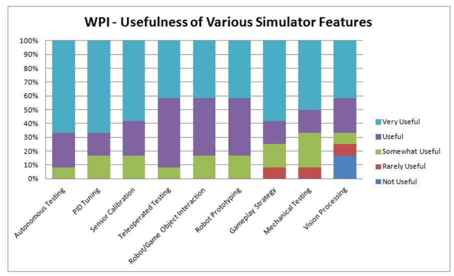

Figure 17: WPI - Usefulness of Various Simulator Features

Respondents ranked autonomous testing and PID tuning most useful with mean scores of 4.58 and 4.50 respectively. Standard deviations (SD) for these results were 0.67 for autonomous and 0.80 for PID tuning. The lowest ranked features were Mechanical Testing and Sensor Calibration. It is important to note where teleoperated testing ranked, as it was ranked the highest for both Granite State and Groton Districts. Teleoperated testing had a mean of 4.33, below autonomous testing and PID tuning, as well as gameplay strategy (4.42 mean). Its SD was 0.65, the lowest of all the features, while PID tuning and gameplay strategy had standard deviations of 0.79 and 1.06, respectively, which equates to less consensus amongst teams. This would suggest that teams find simulations that mimic some FRC competition play and some individual component testing more useful than others; however none of the means are below "Somewhat Useful", and all but Vision Processing are below "Useful", indicating

Gazebo Feature	Mean	SD
Autonomous	4.58	0.67
PID Tuning	4.50	0.80
Sensor Calib.	4.42	0.79
Teleoperated	4.33	0.65
Game/Obj. Manip.	4.25	0.75
Protoryping	4.25	0.75
Strategy	4.25	1.06
Mech. Testing	4.08	1.08
Vision Process	3.67	1.56

Table 15: Statistics of Gazebo Features at WPI

that some teams still have use for such features, and that WPI may be an outlier in comparison to other district events and the teams that compete there. An additional feature that one respondent suggested was a networking capability in order to host matches between robots with individual people controlling each robot.

Gazebo	Mean	SD
Functionality	8.30	1.49
Usability	8.30	1.42
Utility	8.90	1.14

Table 16: WPI - Gazebo Demo Feedback Statistics

Gazebo Demonstration Feedback

Of those that took the survey, 83% ran the simulator. Those respondents were asked to rate the simulator for functionality, usability and utility on a scale of 1 to 10, with 1 being very poor and 10 being very good, based on their experience running it, and the statistics from those responses can be seen in Table 16. Based on this, respondents found the simulator to be very workable, user-friendly, and useful on average, but disagreed on the extent, as can be seen by such large SD values as compared to what had been seen at Granite State and Groton.

WPI District Summary

All respondents remarked that they would use the simulator if made available to them. In asking about when the simulators would be most used, majority responded during build season, as Figure 18 shows. Asked what they would use it for, most responses took the form of testing and building code for the competition robot as its being built. Other responses included for teaching programming and in training new drivers.

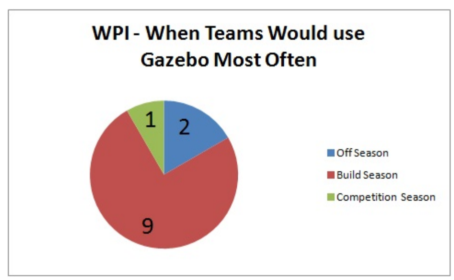

Figure 18: WPI - When Teams Would use Gazebo Most Often

Key features they most desired are those that mimic some FRC competition components, such as autonomous mode, and some specific type testing such as PID tuning. However, these are in contrast to Granite State and Groton competitions, which emphasized mimicking FRC competition completely over component-specific testing and would lead WPI to be an outlier. Exact results and statistics from this survey can be seen in Appendix A.7.

4.1.4 Rhode Island Regional Survey Results

There were a total of 40 respondents recorded at the Rhode Island Regional and are shown by Table 17. It is important to note that majority of the respondents for this survey were from the same team, and that there are only 12 unique teams represented in these results. Most questions, however, are on an individual basis, and only a few questions are based on the overall team, and the responses have been filtered to represent the 12 teams appropriately. Each respondent gave general background on what they did in respect to their team, what type of programming and CAD software their team uses, and if they have ever used a simulator in the past. These results are seen in Table 18.

Student	**Mentor**
28	12

Table 17: Rhode Island - Respondents

Position on their FRC Team				
Programmer	**Electrician**	**Mechanic**	**Designer**	**Other**
8	4	14	1	13

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
3	5	2	1	1

Simulators Used in the Past			
None	**5^{th} Gear**	**LabVIEW Sim**	**Other**
29	1	9	2

Programming Language Used			
Java	**C++**	**LabVIEW**	**Other**
9	1	4	1

Table 18: Rhode Island - General Background Information

The majority of responses were from students. Unlike previous events, the majority of respondents were "Mechanic" and "Other", and overall much more diverse primary positions. Those listing as "Other" would include respondents that were in non-specified fields such as marketing or business for the team, or found themselves in multiple roles without an actual primary position. In listing what type of CAD software their team uses, most teams did use some type of software, with SolidWorks the more dominant, however 25% did not use a CAD program at all. This would show that some teams have the tools to design a custom robot that could be imported into Gazebo for testing, but others, a quarter of the responses received from this event, do not. Majority of respondents did have not used a simulator in the past, in which Gazebo would be the first. In asking what programming language is used, majority of respondents listed Java like at Granite State; but overall diverse with C++ and LabVIEW programmers that responded as well.

Linux Experience

The responses are shown in Figure 19, with a mean of 2.43 and standard deviation (SD) of 1.26. With the average between "No Experience" and "Little Experience", this would suggest that teams would require great assistance in terms of Linux and debugging the software should issues arise, with simplified installation and documentation. The high SD shows a few are knowledgeable with Linux, but because of the low average, majority would not be at or above "Proficient".

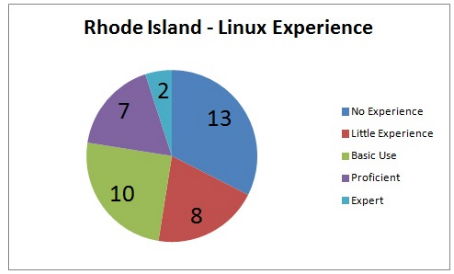

Figure 19: Rhode Island - Linux Experience

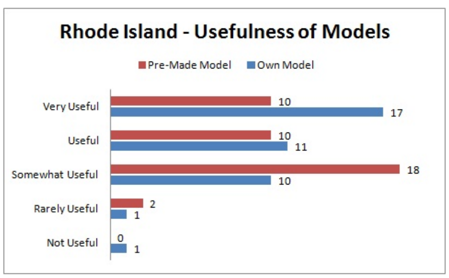

Figure 20: Rhode Island - Usefulness of Models

Custom vs. Pre-Made Models

There was a notable preference for importing custom models as Figure 20 shows. On a rating scale of 1 to 5, with 1 being "Not Useful" and 5 being "Very Useful", the mean scores were 4.05 and 3.70, respectively, with the SD for each at 1.01 and 0.91. This means that there was a small lead towards importing teams' own models into Gazebo, and the standard deviations, while higher than the previous regionals in terms of importing their own robot models, are too close to each other to demonstrate a greater consensus for one or the other. Though it should be noted that at this regional, a higher SD on importing their own robot models may be indicative of the higher proportion of teams that don't use any CAD software, which would make that type of testing within Gazebo useless. This supports both documenting and making effective the ability to import teams' own robot models into Gazebo as well as having pre-made robot models available.

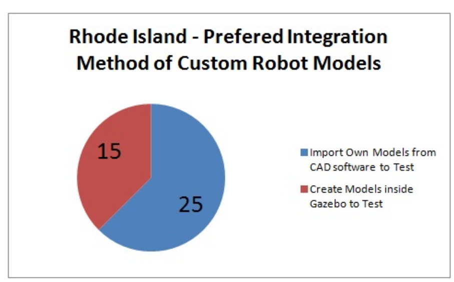

Figure 21: Rhode Island - Integration Method

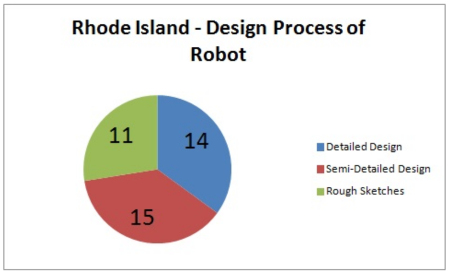

Figure 22: Rhode Island - Design Process

Modeling Integration

When asked how they would like to integrate a design into the Gazebo simulator, most chose to first develop a robot in CAD, and then export it into Gazebo for testing as is shown by Figure 21. These data support the notion that teams would rather design their robots within a known CAD program to export into Gazebo than to create it within Gazebo though a plugin.

Teams were also asked about their design processes. All three options were well-represented, as shown in Figure 22. Gazebo should be prepared to accommodate all three types if it is to be usable by these teams.

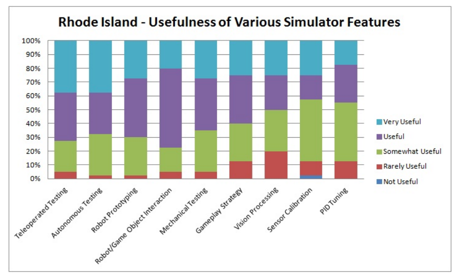

Figure 23: Rhode Island - Usefulness of Various Simulator Features

Desired Simulation Functions

Responses can be seen in Figure 23. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 19.

Respondents ranked teleoperated and autonomous testing most useful with mean scores of 4.05 and 4.03, respectively. Standard deviations (SD) for these results were low, with teleoperated testing having a slightly higher SD of 0.90 to autonomous testing at 0.89. The lowest-ranked features were PID tuning and sensor calibration, with means of 3.50 and 3.53, respectively, and standard deviations of 0.93 and 1.06. Additional features that respondents listed they would like to see include multiple joystick and controller drivers available for use, a better wheel friction model, and a fast-help resource tool.

Gazebo Feature	Mean	SS
Teleoperated	4.05	0.90
Autonomous	4.03	0.89
Protoyping	3.95	0.81
Game/Obj. Manip.	3.93	0.76
Mech. Testing	3.88	0.88
Strategy	3.73	0.99
Vision Process	3.55	1.08
Sensor Calib.	3.53	1.06
PID Tuning	3.50	0.93

Table 19: Statistics of Gazebo Features at Rhode Island

Gazebo	Mean	SD
Functionality	7.79	1.64
Usability	7.39	2.03
Utility	8.18	1.79

Table 20: Rhode Island - Gazebo Demo Feedback Statistics

Gazebo Demonstration Feedback

Of those that took the survey, 83% ran the simulator. The statistics from those responses can be seen in Table 20. Based on this, overall respondents found the simulator much more useful and usable; however with usability at such a high SD, this may be impacted by each respondent's either familiarity or unfamiliarity with Linux based systems and workings. In fact, the SD for each rating is higher than ideal. However, with a low experience level of Linux as found earlier by respondents background information, a low mean usability score is expected.

Rhode Island Summary

All respondents noted they would use the simulation if available to them, and in asking about when the simulators would be most used, a majority responded during build season, as Figure 24 shows. Asked what they would use it for, the biggest use was to test code during build season, and to use it as a programming learning tool. Other notable uses included drive training and practice, field manipulation, and developing game strategies.

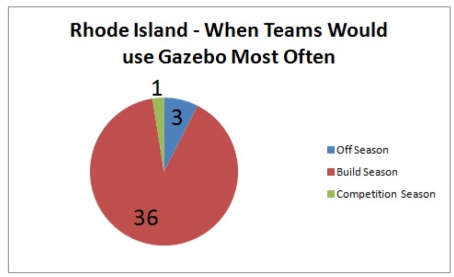

Figure 24: Rhode Island - When Teams Would use Gazebo Most Often

Key features respondents most desired are those that mimic an FRC competition, such as teleoperated and autonomous modes, with less emphasis on specific type testing such as PID tuning or sensor calibration. Exact results and statistics from this survey can be seen in Appendix A.7.

4.1.5 Overall District Event Results

Looking at all the data received from the four competition events, the IQP team received a total of 69 individual respondents, shown by Table 21, from 36 unique teams. Table 22 gives the overall background of the individuals and teams surveyed.

Student	Mentor
45	24

Table 21: Overall - Respondents

Position on their FRC Team				
Programmer	**Electrician**	**Mechanic**	**Designer**	**Other**
25	7	18	2	17

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
10	20	12	5	2

Simulators Used in the Past			
None	**5^{th} Gear**	**LabVIEW Sim**	**Other**
52	1	13	4

Programming Language Used			
Java	**C++**	**LabVIEW**	**Other**
31	5	8	3

Table 22: Overall - General Background Information

The respondent's positions were mostly in programming, but mechanical positions and "Other" followed closely creating a somewhat diverse group of backgrounds. Those listed as "Other" may include respondents that were in non-specified fields such as marketing or business for the team, or found themselves in multiple roles without an actual primary position. In listing what type of CAD software their team uses, programs were diverse between SolidWorks, Autodesk Inventor, PTC, and "other", with SolidWorks being used the most. However, 28% noted they used no CAD program at all, showing that while most teams have the tools to design a custom robot that could be imported into Gazebo for testing, over a quarter of the responses received from these events, do not. A majority of respondents had not used a simulator in the past, and of those that did, most used the LabVIEW Simulator. In asking what programming language is used, a majority of respondents listed Java, with C++ and LabVIEW both in the minority. The high representation of Java teams is likely due to the survey being used to collect teams for the beta, and thus does not reflect the actual distribution of programming languages used in FRC.

Linux Experience

With Linux experience on a scale from "No Experience" to "Expert", the responses are shown in Figure 25 with a mean of 2.62 and standard deviation (SD) of 1.32. With the average between "Little Experience" and "Basic Use", this would suggest that teams would require great assistance in terms of Linux and this supports the

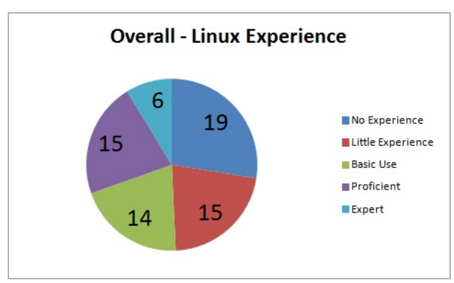

Figure 25: Overall - Linux Experience

need for referencing material and documentation for teams to become acquainted with Linux (particularly Ubuntu) and the software they would be working with, such as Gazebo, if they are to have a positive and successful experience with it.

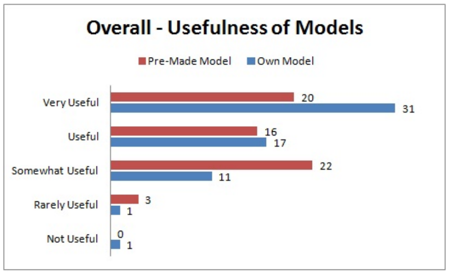

Figure 26: Overall - Usefulness of Models

Custom vs. Pre-Made Models

Between custom made and pre-made robot models, overall there was a notable preference for importing custom models as Figure 26 shows. On a rating scale of 1 to 5, with 1 being "Not Useful" and 5 being "Very Useful", the mean scores were 4.25 and 3.87, respectively, with the SD for each at 0.84 and 0.87, respectively. This shows that, overall, teams desire to import their own models more than pre-made models in testing, though pre-made models still scored highly in the usefulness scale, most likely for teams that don't work with CAD software. The SD for each are close representing a similar consensus between both opinions. [13]

Model Integration

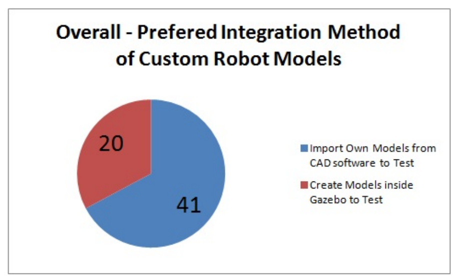

Figure 27: Overall - Integration Method

Between importing a robot into Gazebo from a CAD program and creating a robot right within Gazebo to test, a majority of respondents desired to import their own CAD models, as is shown by Figure 27. It can be inferred that teams would rather use a design program they are familiar with and already use versus learn a new one within an entirely different operating system. However it is important to note that those who would prefer to design in Gazebo through a plugin are mostly of those that did not use any CAD software at all, or do not have the time or student resources to design a robot in CAD. [14]

As can be seen in Figure 28, different styles of designing are practiced by multiple teams, though slightly more teams prefer initially-detailed designs. This shows a diverse form of robot design processes, and that Gazebo should be prepared to adept and be able to accommodate all

[13] Out of 61 respondents, as Granite State did not have this question presented
[14] Out of 61 respondents as Granite State did not have this question

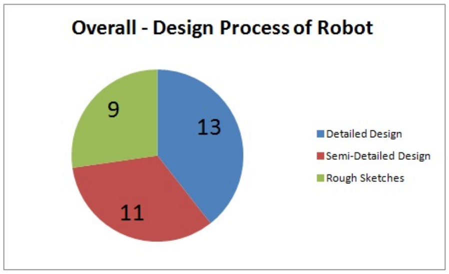

Figure 28: Overall - Design Process

three types if it is to be usable by these teams, and give precise and simplified documentation on the steps required in order to import a CAD model based on those designs. [15]

Desired Simulation Functions

The aggregate usefulness ratings of the simulator's features can be found in Figure 29. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 23.

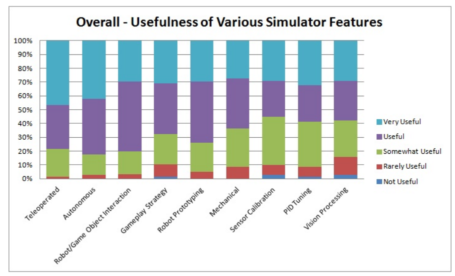

Figure 29: Overall - Usefulness of Various Simulator Features

Overall, respondents ranked teleoperated and autonomous testing most useful with mean scores of 4.23 and 4.22, respectively. Standard deviations (SD) for these results were low, with teleoperated testing having a lower SD of 0.65 to autonomous testing at 0.75. The lowest-ranked features were vision processing and PID tuning. This would suggest that overall, teams find simulations that mimic FRC competition play more useful than individual component testing, as the top four features are those that deal specifically with the FRC game. However, the lower-ranked features still have mean scores above "Somewhat Useful," indicating that teams may still have use for such features. Additional features teams suggested most included the use of additional robots to be used and driven simultaneously, with a repository for community sourced components and a fast help resource.

Gazebo Feature	Mean	SD
Autonomous	4.23	0.75
Teleoperated	4.22	0.65
Game/Obj. Manip.	4.07	0.70
Strategy	4.03	0.55
Protoyping	3.92	0.70
Mech. Testing	3.83	0.64
Sensor Calib.	3.83	0.66
PID Tuning	3.75	0.73
Vision Process	3.68	0.60

Table 23: Statistics of Gazebo Features Overall

[15]Out of 29 team respondents as Granite State did not have this question

Gazebo	Mean	SD
Functionality	8.01	0.89
Usability	7.73	0.44
Utility	8.65	0.33

Table 24: Overall - Gazebo Demo Feedback Statistics

Gazebo Demonstration Feedback

Of all that took the survey, 81% ran the simulator. The collective responses can be seen in Table 24. This shows that, overall, users of the simulator at the events found the simulator to have a very high potential for use amongst their team, but the usability of the simulator was less impressive and scored the lowest mean. Both had low SD values, indicating more consensus amongst the users. The functionality ranked in the middle by mean, and had the highest SD. This may have been skewed by the lack of a graphics card being run during the early events, which was later fixed.

Every respondent noted they would use the simulation if available to them, and majority would use it during build season, as Figure 30 shows. Most respondents said they would use it to test programs for the final competition robot while it was being built during the "Build Season". Other notable and popular uses included training new programmers and drivers as well as to develop gameplay strategy. One notable mentor responded that they would use it for the classroom, to teach various aspects of the engineering field.

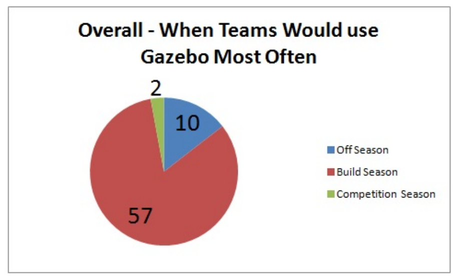

Figure 30: Overall - When Teams Would use Gazebo Most Often

4.2 Beta Participant Survey Data

This section delves into how the FRC teams and students that joined the beta program used Gazebo, and how it performed within the season. Results obtained in the following subsections include information on the beta teams' initial experience going into the beta, the progress they have made, and finally their overall opinions of how well Gazebo performed and improvements that need to be made before its release.

4.2.1 Pre-Beta Results

As FRC teams were recruited for the beta, they were given a survey to fill out before the delving into the documentation and installing Ubuntu and required programs. From twenty three teams that started the survey, only ten beta participants completed, with an additional three partial responses were collected. Majority of respondents were mentors, as can be seen in Table 25.

Student	Mentor
5	8

Table 25: Pre-Beta Respondents

Simulators Used in the Past			
None	5^{th} Gear	LabVIEW Sim	Other
10	1	1	1

Table 26: Pre-Beta Previous Simulator Uses

Beta participants were asked about previous simulator uses in the past. Based on Table 26, a majority of respondents had never used a simulator before. The one that marked "Other" noted that it was a self-made simulator for the team.

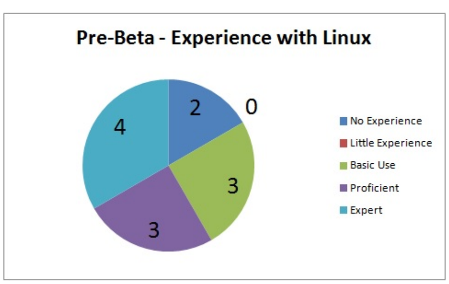

Figure 31: Pre-Beta - Linux Experience

With Linux experience on a scale from "No Experience" to "Expert", the twelve responses are shown in Figure 31 with a mean of 3.58 and standard deviation (SD) of 1.44. This shows that on average, beta testers will have some knowledge in troubleshooting basic Linux bugs and issues, with two individuals having no experience at all. The ten that do have at least "Basic Use" of Linux all noted that had used Ubuntu before. Only one of the twelve noted that they would not be able to install Gazebo on a team accessible machine. In trying to determine hardware specifications of the beta teams' computers, the average CPU (Central Processing Unit) was between an i5 and i7, and GPU (Graphic Processing Unit) was an Nvidia 600 series. The slowest CPU and GPU listed were an i3 and AMD Radeon HD 5570, respectively. All beta participants had at least 10GB of hard drive space for use on their machines for installations. The team using the slowest CPU did not respond to later surveys in the beta, but the team with the slowest GPU reported a 5 on a scale from 1-10 on simulator performance. This suggests that all teams within this testing group at least had a graphics card that could run Gazebo, though not at a high framerate and time scale.

Various features including general parameters that would mimic an FRC competition or experience and others more specific to certain aspects and situations that could be tested were rated, each on their usefulness from "Not Useful" to "Very Useful", and their responses can be seen in Figure 32. These features are ranked by the highest mean value, with the lowest SD as a tie breaker, and shown in Table 27.

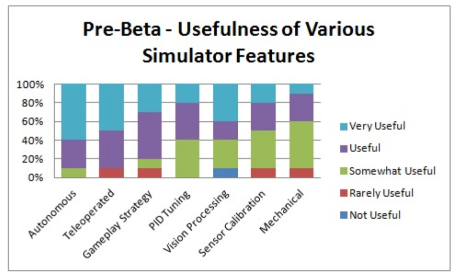

Figure 32: Pre-Beta - Usefulness of Various Simulator Features

From the ten beta participants, autonomous and teleoperated testing were listed as the most useful with mechanical eesting and sensor calibration the least. Thus, in testing this simulator, it would be expected that beta participants place a greater value on testing their autonomous and teleoperated code over any other feature, and in mimicking an FRC game over testing specific robot features. It is important to note that other features are not scored low, and are ranked at least "Somewhat Useful", but some do have a high SD which indicates discrepancies amongst how beta participants rank their value in usefulness.

Gazebo Feature	**Mean**	**SD**
Autonomous	4.50	0.71
Teleoperated	4.30	0.95
Strategy	4.00	0.94
PID Tuning	3.80	0.79
Vision Process	3.80	1.73
Sensor Calib.	3.60	0.97
Mech. Testing	3.40	0.84

Table 27: Statistics of Gazebo Features from Pre-Beta

Respondents were also to give background information on their use of CAD in designing their robot. Table 28 shows what the respondents use on their team, and if they use a SolidWorks, what they use it for. With majority of teams using

CAD Software Used				
None	**SolidWorks**	**Autodesk**	**PTC**	**Other**
2	5	5	1	1

What SolidWorks is Used For				
Manufacturing	**Show Sponsors**	**Show FRC Judges & Teams**	**Animate**	**Other**
4	2	3	3	2

Table 28: Pre-Beta - CAD Background Information

CAD, half of which using SolidWorks, they would have the ability to design a robot that could be imported into Gazebo to test with the proper constraints and definitions.

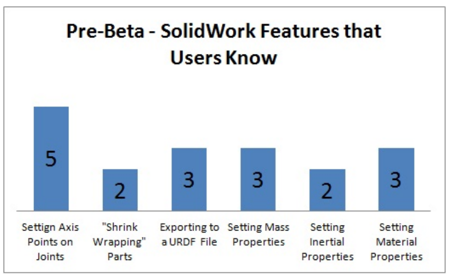

Figure 33: Pre-Beta - SolidWorks Features

Those that used SolidWorks, being the supported CAD software for importing into Gazebo during the end of the beta, were asked if they knew certain features that would ultimately be used in exporting a robot model, and is illustrated in Figure 33. Many knew of the various features, and all noted that they knew how to set axis points on joints of their robot. This shows that these beta-teams would have some basic knowledge required for later additions of Gazebo to be tested. Exact results and statistics from this survey can be seen in Appendix B.2.1.

4.2.2 During-Beta Results

Results received during the beta came in three different surveys. A short questionnaire for teams to fill out during build season, a longer more in-depth questionnaire after build season had ended, and a second short questionnaire during competition season. The following subsections detail these surveys.

4.2.2.1 During Build Five weeks into the build season, beta teams were given a small four-question status update survey to address their progress in running the simulator at that point. There were 6 beta teams that completed this survey, mostly student respondents, and only 2 had used the simulator in that time. The major issues that held up some teams from using the simulator were issues in installing the software and ROS scripts. Other teams noted that they simply did not have time to go through the installation process and try the simulator for use.

4.2.2.2 Post-Build In the one-week period between build season and competition season, beta teams were given a more in-depth survey of how they used and would rate the Gazebo Simulator thus far. Four teams completed the survey, with two additional partial responses. Half were students and the other half mentors, as can be seen in Table 29. All respondents had noted that they used Gazebo during build season, with half using it for 1-3 hours and the other half for 4-6 hours. However in that time, majority were simply installing or troubleshooting the software. Only one responded that they had coded and simulated the given robot.

Student	**Mentor**
3	3

Table 29: During-Beta Respondents

The one individual who had simulated a robot used it for teleoperated testing. The respondent rated the functionality as "Usually Worked", the usability as "somewhat hard to use", and the utility as "somewhat effective". It was also noted that the most difficult part of Gazebo was exporting their own robot as they didn't have a 64-bit Windows computer to run SolidWorks on for the plugin, and the hardest part to understand was the installation process, described as "convoluted".

In the four completed responses, the documentation was described as "very clear and straightforward", save for getting Ubuntu 13.04 installed, which was marked between "very clear" and "somewhat clear". Respondents that looked to outside resources for assistance were having issues with installing Ubuntu.

Improvements to Gazebo recommended by respondents included more functionality and making it more user-friendly. Only half of the respondents asked for assistance from the development team, one noting "somewhat helpful" and the other noting "extremely helpful". Last comments made by teams included the excessive amount of time it is taking to debug the installation and systems, as well as trying to get the WPI libraries to work with the robot simulation on Gazebo. Exact results and statistics from this survey can be seen in Appendix A.7.

4.2.2.3 During Competition Three weeks into the competition season, beta teams were given a second small status update survey to briefly address their progress in the running the simulator. Only three completed responses were made, with an additional partial response, all of which were from students. Of the four individuals, two used the simulator. For one team that had used the simulator, issues arose with having the correct Linux version installed (having

13.10 installed instead of 13.04 which was required). They proceeded to using a Virtual Machine (VM), but had not fully tested Gazebo due to its memory consumption through a VM. Of those that did not use or try to use the simulator, the issues were not having enough time. One respondent said that they would have used the simulator if it was compatible with Windows rather than Linux.

4.2.3 Post-Beta Results

Post-Beta data was collected in two ways: Teams were sent a Qualtrics survey to fill out, and teams were questioned in person at the New England FRC Region Championship at Boston University. The following subsections go into detail about each.

4.2.3.1 Post-Beta Survey Results From the survey, there were seven complete responses, most of which came from students.

Tracker	Number of Respondents that Completed
Installing Linux	5
Install Gazebo	3
Run GearsBot Sample Code in Gazebo	3
Edit and Test GearsBot Sample Code	1
Completed Task: Behind the Box	0
Did not Complete any Trackers	2

Table 30: Post-Beta Trackers Completed

Table 30 illustrates the various trackers that beta teams completed, in chronological order from installing Linux to the "Behind the Box" task. The three testers that competed trackers past installing Linux were asked to rank from 1 to 10, with 1 being very poor and 10 being very good, the Gazebo Simulator utility, usability, clarity of documentation, complexity of installation, and simulator performance. The results can be seen in Table 31. The simulator utility ranked the highest, indicating that for what the simulator could do in respect to how teams would use it, it was well received. The lowest ranked mean was the Gazebo usability, indicating that for beta teams, the simulator was difficult to operate. It is important to note that the Gazebo usability also had the lowest SD, indicating that it had the most consensus upon where it was ranked compared to other aspects. The clarity of documentation had the highest SD, indicating a wide distribution of how the documentation was interpreted.

When asked if they would use the simulator in the future, all but one said they would use it.

	Mean	SD
Gazebo Usability	6.67	1.15
Gazebo Utility	7.67	1.53
Documentation Clarity	7.00	3.00
Installation Complexity	7.00	2.00
Gazebo Performance	7.00	2.00

Table 31: Post-Beta Feeback Statistics

For those that would use it in the future, they would use it mainly for testing robot software and code to visualize mechanical design and movement of the robot during build. The individual that responded they would not use it pointed to issues in changing the code in a fashion that would not be applicable to the actual robot, and thus the simulator would have no use for their team. This individual listed a few changes that would make Gazebo more usable for their team, including compatibility with Windows and the ability to use the virtual robot with the SmartDashboard.

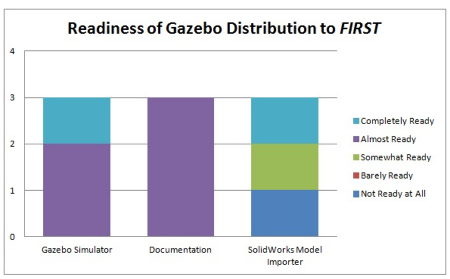

Figure 34: Post-Beta - Simulator Distribution Readiness

Of the three that competed trackers past installing Linux, they were asked to rate the readiness of the Gazebo Simulator, its documentation, and the SolidWorks model exporter to be distributed to all of FIRST. As Figure 34 shows, the "SolidWorks Model Importer" had a low mean readiness score and a high SD. The Gazebo Simulator and its documentation were rated as closer to being completely ready for distribution, with high means and low SDs, particularly on the documentation. If the entire process could be simplified, the Gazebo simulator would be ready for all of FRC, according to these three beta testers.

Additional features that the beta responders wished to see included support for additional development environments, as well as support for a Windows version. Of the seven beta responders, only 4 utilized development team support through TeamForge, and all of them found the support given to be extremely helpful. In asking how to further improve the simulation or documentation, previous points were re-advocated such as streamlining the documentation and installation process, as well as to the capability to program in additional languages, such as C++. More specific system requirements were also requested. Exact results and statistics from this survey can be seen in Appendix A.7.

4.2.3.2 Post-Beta New England FRC Region Championship Results

At the New England Championship District, four beta teams were found and questioned in general on their use and opinion of Gazebo. Only one responded that they had used the simulator, and said that they were able to drive GearsBot in teleoperated mode. That individual noted that additional improvements should include a realistic world where parts and applications could break and cause failure (e.g. motors stall or belts/chains break) as would happen in an actual competition. Among all four surveyed at the District, there was consensus on the timeframe of which to start using Gazebo. While all noted that they would use it during the build season for testing code, they all desired to install and run it prior to build season so that they would be completely ready and understanding of the software before build season began. Two of the four mentioned issues with Linux installation, and that a more recent version of Ubuntu should be used.

4.3 Response Rates

The following section summarizes information on participation in each survey, and explains the possible reasons for each response rate. Then, analysis is provided in order to propose possible solutions to the generally low response and participation rates observed over the course of the beta.

Survey	**Distribution**	**Expected Participants**	**Actual Participants**
Pre-Beta Survey	Electronic	66	10
Beta Status Update	Electronic	13	4
Post Beta Survey	Electronic	66	7
Competition Demonstration	In Person	149	69

Table 32: Survey Response Rates

For the Expected Participants in Table 32, the number corresponding with the Pre-Beta Survey is the total number of individuals registered over the course of the beta. The number corresponding with Beta Status Update is the number of original beta testers, while the Post Beta Survey is the total number of individuals emailed with the survey link. Lastly, the number associated with the District Competition Demonstrations is the total number of teams as the events that were visited.

Event Name	**Registration Method**	**Beta Testers Registered**	**Registered Testers to TeamForge**	**Post-Beta Survey Responses**
Groton	Survey	5	0	0
WPI	Survey	10	0	0
Rhode Island	Survey	22	0	2
Northeastern	In Person	6	6	1
Pre-Season	Email	13	13	2
Totals	-	66	21	7

Table 33: Beta Team Registrations

Table 33 documents the methods and schedule for registering participant throughout the entire project. Note that only two participants from all of the live demonstrations where participant were asked to sign up for TeamForge on their own time ended up successfully registering. Conversely, there was a 100% retention rate on TeamForge users who signed up at the Northeastern event, where they were asked to create accounts in person. For further discussion of these results, please see Section 5.2.1 on TeamForge Usage.

5 Discussion

This chapter analyzes the results discussed in the previous chapter. The analysis is split into two parts; first recommendations based on the survey results from demonstrations are explained. Next, the results of the practical Gazebo beta test are analyzed. This discussion explains many of the results from Chapter 4, and the following chapter uses the discussion and results to list recommendations for improving Gazebo for future releases.

5.1 Theory

The following analysis summarize survey data collected from students and mentors from the district competitions who got a chance to see a demonstration of Gazebo, but did not necessarily use it in practice. The results suggest that a simulator capable of using customized robot designs is highly appealing to FRC teams. Among teams surveyed, the most popular possible applications of Gazebo were testing their autonomous and teleoperated code, followed by examining game strategies. This suggests that much of the current functionality of Gazebo itself is appealing to teams, as they were able to test custom teleoperated and autonomous code in the demonstration. Examining game strategies involves importing and controlling multiple robots in Gazebo at once, which would be a good secondary task for the development team to pursue next. Recommendations for the next development tasks based on these theoretical results may be found in Chapter 6.

5.2 Practice

This section analyzes survey data collected from FRC students and mentors who attempted to install and use Gazebo as part of the beta test, and the feedback that was received from them. The lack in amount of desired results is also noted upon in relation to how response rates are normally met and how to be improved upon.

5.2.1 Gazebo Usage

The response rates and TeamForge forum activity was extremely low, as discussed later in Section 5.2. The most common explanations for why teams were not using the simulator cited in the status updates were lack of time during build season and lack of compatibility with Windows. While the latter issue cannot be addressed, some solutions to the former were suggested by two of the teams interviewed at the Boston University District Championships. These individuals suggested that Gazebo be released months before build season so teams could install and familiarize themselves with the tool before being expected to use it to improve their designs or test code. The primary issue causing teams to not use Gazebo was lack of time. Prioritizing release scheduled for the Fall of 2014 could address this problem. Simplifying the overhead involved with using Gazebo (e.g. installation and learning curve) could also mitigate the issue of not having enough time to fully use Gazebo.

5.2.2 TeamForge Usage

TeamForge was the primary distribution method for world files, premade robots and sample code, but it was not frequently used by beta testers. The IQP team had a 100% TeamForge sign-up rate for people who registered at the Northeastern competition, where the IQP team had them create accounts for TeamForge in person and then later added them to the project. From all of the other districts, the IQP team only had two students contact us with TeamForge usernames after the IQP team provided registration instructions to all teams that expressed interest in participation in the survey.

One possible explanation for this extremely low retention rate is the timing; when asked at the Boston University District Championship, most of the participants said they did not have enough time to use the simulator during competition season. Several of the students and mentors surveyed reported that they would be more likely to use the simulator if they received it before build season and had ample time to familiarize themselves with the interface before trying to use it as part of their build cycle.

Another possible explanation for the slow response rates is that there were too many registration steps involved in acquiring all of the files needed to run Gazebo. In general, it is easier to hold participants accountable for all of the required registration processes if they are conducted in person. As a result, the IQP team were very unsuccessful in getting completed TeamForge registrations from competitions where the IQP team asked the testers to create accounts on their own time.

5.2.3 Response Rate Improvement Research

Existing research supports several of the methodologies used in this study to increase response rates. Several hypotheses in a report entitled "Survey response rate levels and trends in organization research" explain some of the response rates observed in this study. For example, as part of our methodology the IQP team included a raffle for a gift card incentive to increase the response rate of the final survey, and incentivize teams to spend more time completing trackers. The findings of Baruch and Holtom's paper demonstrate that this is an effective means of increasing response rate: "personalization, pre-paid or promised incentives, monetary and non-monetary rewards have also been found to increase response rates"[16]. When the raffle was introduced, the number of respondents increased from zero to seven. While this response rate was still relatively low based on the number of individuals contacted about the final survey, the incentive did provide some data to work with.

The results of this study also suggest that surveys conducted in person generally see a much higher response rate than those conducted over the internet or mail: "surveys that are completed in person or on a drop-in basis have a higher RR (62.4%) than internal mail (55.5%) or regular mail (44.7%)"[17]. This is why the IQP team focused on surveys in person at the district events in order to get the theoretical data for how teams imagine they would use a simulator.

[16] Baruch and Holtom, page 1145, http://hum.sagepub.com/content/61/8/1139.full.pdf+html
[17] Baruch and Holtom, page 1151

The low response rates are not uncommon for surveys of organizations where respondents are representatives of a larger body of people working toward a similar goal. Baruch and Holtom's study writes, "from the present analysis it is clear that studies conducted at the organizational level seeking responses from organizational representatives... are likely to experience lower RR... of approximately 35–40 percent."[18] This level of response rate was also roughly seen in the Brandeis FIRST study, where 46% of students solicited actually responded to the survey.[19] While this research suggests that low response rates are historically expected from organizations, and FIRST in particular, there are some methods including surveying in person and providing monetary incentives that can be used in future related studies to improve response rates. These recommendations are discussed in Section 6.2.1 of this report.

6 Conclusion

This chapter lists recommendations for improving Gazebo based on the analysis discussed in Chapter 5 and results from Chapter 4. These recommendations are split into two parts: development and marketing. Development recommendations are relevant to the students who will be working on improving Gazebo over the Summer of 2014. Marketing recommendations explain how the simulator should be explained to teams and are relevant to *FIRST*.

6.1 Development

The following subsections describe issues that could be addressed by changes to Gazebo or the Gazebo Plugin itself. These recommended changes would improve Gazebo for future release to all FRC teams.

6.1.1 Ubuntu Version

Gazebo needs to operate on a supported version of Ubuntu. Using an unsupported operating system such as 13.04 can lead to security risks. On top of this, 13.04 in particular has problems with graphics drivers, making it a particularly poor choice for Gazebo, which requires extensive use of graphics hardware. The IQP team wrote an install script for Ubuntu 13.10 (see Appendix D.1). This is not a permanent solution, as Ubuntu 14.04 has recently been released and might

[18]Baruch and Holtom, page 1155
[19]BRANDEIS STUDY, PAGE 3

be considered as an operating system for the FRC Gazebo Plugin, but it may help in the short term for further beta testing.

6.1.2 File Distribution System

The underuse of TeamForge suggests that in the future, Gazebo should either move to another, easier file sharing platform, or remove steps that require teams to sign up for services to receive necessary files. A possible alternative would be to include all programs and extra files such as sample code and World files in a custom LiveCD. Files related to game objects could be released and encrypted, or they could require teams to download them from the *FIRST* website after the game has been released.

6.1.3 Simplifying the Installation Process

During the course of the beta, teams were asked to install Ubuntu 13.04 and run a number of different installation scripts. While most teams claimed that the installation process was not a significant barrier, installation testing results suggest that it constitutes a large time commitment. The most common reason that teams gave for being unable to test Gazebo during the beta period was a lack of time, and many said that they would have used it if they could have had it set up earlier. Thus, improvements to the speed and ease of installation are necessary.

Possible solutions recommended by the Gazebo Plugin Development Team include distributing the most recent versions of Linux (currently 13.10 and 14.04), Gazebo and ROS in a custom LiveCD. A custom LiveCD is an installation disk modified to install additional software and files upon installation. Feedback from one of the teams at the Northeastern regional revealed compatibility errors between the 32-bit version of Ubuntu and Gazebo, so this means the distributed version of Ubuntu must be 64-bit. Including a custom Ubuntu disc image on an installation disc can eliminate possible Ubuntu version compatibility errors in addition to reducing the number of teams that neglect to use Gazebo because of time constraints.

While LiveCD is a viable option, it is still important that this not be the only method of installation. A select few teams already have an Ubuntu install, and wish to install the system on their existing operating systems. Expanding operating system compatibility so these users don't have to install a new version would be ideal.

It is worth noting that several respondents across all of the surveys requested Windows compatibility for Gazebo. This could be due to having little experience with Ubuntu, or not having a machine that they could install Ubuntu on. Unfortunately, Gazebo is not compatible with Windows, so creating a port for Windows is not a viable use of the development team's time. While the latter of the two issues suggested is impossible for the development team to address, simplifying the installation process can reduce the challenges faced by teams that want to use Gazebo with little Ubuntu experience. At a meeting with the development team on April 16th, 2014, a developer suggested that a good metric for installation simplification would be that the teams would not have to use the terminal window in Ubuntu at all during the installation process. Conducting this test with a controlled group of students at WPI and then expanding it to a larger base of FRC teams would be a viable task for a future Gazebo IQP team.

6.1.4 Improving Import and Export Tools

Gazebo's ability to use customized robot models together with WPILib code is its greatest advantage over its competitors, but the existing import/export tools are lacking in reliability and quality. The current Solidworks-to-URDF Exporter has only been tested on one robot the size and complexity of a typical FRC robot, and it took two SolidWorks veterans eight hours. Even when used on simple assemblies, a user can struggle for hours due to poor feedback from the exporter. This makes for an unacceptable user experience. In addition, the interface allows for a great amount of customization, but is very clearly geared toward expert users. The target audience of the FRC Gazebo Plugin will not have the time to become expert users of a tool that they will only use a few times per year, so the interface for a new export tool would do well to abandon some versatility in favor of ease of us.

6.1.5 Expanding Compatibility

The current iteration of the plugin is only compatible with programs written in Java, and the only verified model export tool is for SolidWorks. A wider variety of compatible programming languages and CAD formats is necessary in order to encourage use of Gazebo. While many teams use Java as their primary programming language, roughly 20% of teams still use C++ and therefore do not have access to the simulator currently.[20] Our data also show that Autodesk Inventor and PTC Creo are widely used by teams for CAD, in addition to SolidWorks. Expanding

[20] Henning, McLeod and Silberberg 2013, 33

support to these additional platforms is necessary in order to prevent alienation of teams that use them.

6.1.6 Better Cleanup on Exit

Currently when users exit Gazebo, the program does not shut down completely. In order to fully kill Gazebo, a user must open a terminal and use 'SIGKILL' to end the lingering processes. The network table remains polluted for about 30 seconds after each run, causing Java to throw socket related exceptions if the program is killed then immediately run again. This is a relatively simple issue, but one the development team needs to address.

6.2 Marketing and Research

The following recommendations affect the process of releasing and investigating Gazebo in the future. They provide suggestions for how to improve survey response rates for future research into improving Gazebo, and how to encourage teams to use Gazebo successfully.

6.2.1 Improving Survey Response Rates

Improving survey response rates is necessary for future research related to this topic, and also getting feedback to help guide the development of Gazebo. It was difficult to get strong response rates for surveys that were conducted entirely online. There was a very low completion rate for the online surveys; only 10 of the 23 individuals (43%) who started the Pre-Beta Survey actually completed it. Similarly, only 4 of the 7 individuals who started the Mid-Season Survey completed it, and around that time we were soliciting the 13 original participants so only half of them even started the survey. Even with the raffle incentive there were only 7 complete responses, and at that time all 66 individuals who had expressed interest in the beta at any point were solicited. Attempts to simplify the feedback process for respondents by giving them to option to answer a few basic questions in an email (See Appendix A.7) resulted in no responses.

Conversely, when surveys were conducted in person, we had a nearly 100% completion rate. Only one individual did not complete the survey in person over all of the events that we attended. This suggests that completing surveys and getting feedback in person is the best method for reliably getting responses, even when incentives are provided for online surveys.

A number of anecdotes from the process of gaining responses from live FRC events support the notion that it is hard to successfully get responses from FRC teams over the internet alone. One individual registered for the beta at the Rhode Island District competition and was given a ScreenSteps account to view the installation tutorials. They installed the 32-bit version of Ubuntu 13.04, which had compatibility issues with Gazebo. As a result, they ran into several errors when trying to install Gazebo. Though they were given the gazeboiqp alias and encouraged to email questions to the IQP team, they did not ask for help until the Northeastern District competition, where they approached the IQP team in person. This scenario suggests that even when given resources, teams trying to use Gazebo prefer to seek help in person.

Another individual who was added to the beta at the Groton District event installed Gazebo and completed several of the tasks, but never filled out trackers on TeamForge or provided feedback until spoken to in person at the Boston University District Championship. Both of these anecdotes, coupled with the higher survey response rates from the district competitions, suggest that reaching out to teams in person is a more successful method than expecting them to solicit the IQP team on their own.

6.2.2 Marketing Gazebo for Success

One important part of helping teams use Gazebo successfully is encouraging them to use it in ways that will be helpful to them. In addition to quantitative data, anecdotal evidence suggests that teams would have a variety of uses for Gazebo outside the build season. Many mentors expressed interest in using Gazebo as a low-risk teaching tool for new programming students, as the National Instruments Simulator is used for LabVIEW. According to the Brandeis study, there are 25 participants per FRC team on average, with some teams having as many as 60 student participants.[21] Though the distribution of roles varies from team to team, there are often too many students interested in programming to allow all of them to work directly with software for the robot. This notion is supported by anecdotal evidence provided by mentors and students interviewed at regional competitions who suggested that newer students often do not have enough to do during the build season because teams generally have the more experienced students complete the more significant programming tasks. Gazebo addresses this need for a low-risk teaching tool for new students who do not get as much time with the robot as the more experienced students. Providing sample models would also be sufficient for this use, so it can be

[21] Brandeis University 2011, 3

released to familiarize students with Gazebo and software in general before the robot importer is complete. This use for Gazebo should be encouraged by future teams involved in a wider release of the software. These marketing strategies, coupled with the development improvements listed above will improve teams' success using Gazebo as both a technical and educational tool.

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A Surveys & Trackers

A.1 Pre-Beta Testing

Pre-Beta Survey

Thank you for showing interest in participating in the Beta test for the Gazebo simulator for the 2014 FRC season. This survey is designed to assess your eligibility, background information, and goals for using this simulator for statistical use. Thank you.

What is your FRC team number?

What is your role (as liaison) on the team?

- Student
- Mentor

For those on your robotics team going into the 2014 season, please list how many people are in the designated positions (the number is of people whose primary tasks are these):

Programmers:

Electricians:

Mechanical:

CAD software users:

Have you used a robotics simulator in the past (e.g. 5th Gear, the LabVIEW Simulator)?

- Yes
- No

What robotic simulators have you used (check all that apply)?

- 5th Gear
- LabVIEW Simulator
- Other:

Please describe your level of experience with Linux:

	No Experience	Little experience	Basic use	Proficient	Expert
	○	○	○	○	○

Have you used Ubuntu before?

- Yes

No

Would your school give you permissions to install Ubuntu, a Linux-based computer operating system on a computer your team has access to during build season?

Yes

No

Please list the CPU (Central Processing Unit) of the computer you would install Gazebo on:

Please list the GPU (Graphics Processing Unit) of the computer you would install Gazebo on:

Do you have at least 10 GB of free hard drive space?

Yes

No

Please rate how useful you would find the following simulation functions:

	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful
Autonomous Testing					
Teleoperated Testing					
Mechanical Testing (i.e. drive trains)					
PID Tuning					
Sensor Calibration					
Gameplay Strategy					
Vision Processing					
Other:					

Do you use CAD software?

Yes

No

What types of CAD Software do you use (select all that apply)?

SolidWorks

Autodesk Inventor

- [ ] PTC
- [ ] Other:

What do you use SolidWorks for? (Check all that apply)

- [ ] Manufacturing (e.g. laser cutting, 3-D printing, water jetting)
- [ ] To design a virtual robot to show to sponsors
- [ ] To design a virtual robot to show to other teams and judges at competition
- [ ] To animate a virtual robot or certain aspect of the robot such as its drive train
- [ ] Other:

Which features of SolidWorks does your CAD team lead know about and use? (Check all that apply)

- [ ] Setting axis points on joints
- [ ] "Shrink wrapping" parts
- [ ] Exporting to a URDF file
- [ ] Setting mass properties
- [ ] Setting inertial properties
- [ ] Setting material properties

What are you hoping to get out of the beta testing experience?

A.2 TeamForge Trackers

4/16/2014 TeamForge : artf2540: Install Linux

Artifact artf2540 : Install Linux

Tracker:	Tasks
Title:	Install Linux
Description:	This step involves following the tutorials for installing Linux on the machine you will use for simulation. The steps may be found here: http://wpilib.screenstepslive.com Please post any questions or errors in the process or documentation to the Linux/Ubuntu discussion found at the link below: https://usfirst.collab.net/sf/discussion/do/listTopics/projects.wpilib_gazebo_simulator/discussion.linux_ubuntu_support For guidelines on submitting errors, please see the thread on how to submit an error under the Updates and Resources discussion at the following link: https://usfirst.collab.net/sf/discussion/do/listPosts/projects.wpilib_gazebo_simulator/discussion.updates_and_resources. topc1142 When you have completed this step, please record your team number, completion status and any additional comments on this tracker.
Submitted By:	Lydia Johnston
Submitted On:	04/16/2014 9:15 PM GMT
Last Modified:	04/16/2014 9:15 PM GMT

Status / Comments

Status:*	Open
Category:*	All
Priority: *	4
Assigned To: *	Lydia Johnston
Planning Folder: *	None
Estimated Effort: *	0 Tasks
Remaining Effort: *	0 Tasks

Comments

#1–Lydia Johnston: 04/16/2014 9:15 PM GMT

Action: **Create**

https://usfirst.collab.net/sf/tracker/do/printArtifact/projects.wpilib_gazebo_simulator/tracker.tasks/artf2540 1/1

Artifact artf2539 : Install Gazebo and Related Programs

Tracker:	Tasks
Title:	Install Gazebo and Related Programs
Description:	This step involves following the tutorials for installing Gazebo and all associated programs on the machine you will use for simulation. The steps may be found here: http://wpilib.screenstepslive.com Please post any questions or errors in the process or documentation to the Installation Support discussion found at the link below: https://usfirst.collab.net/sf/discussion/do/listTopics/projects.wpilib_gazebo_simulator/discussion.installation_support For guidelines on submitting errors, please see the thread on how to submit an error under the Updates and Resources discussion at the following link: https://usfirst.collab.net/sf/discussion/do/listPosts/projects.wpilib_gazebo_simulator/discussion.updates_and_resources. topc1142 When you have completed this step, please record your team number, completion status and any additional comments on this tracker.
Submitted By:	Lydia Johnston
Submitted On:	04/16/2014 9:13 PM GMT
Last Modified:	04/16/2014 9:13 PM GMT

Status / Comments

Status:*	Open
Category:*	All
Priority: *	4
Assigned To: *	Lydia Johnston
Planning Folder: *	None
Estimated Effort: *	0 Tasks
Remaining Effort: *	0 Tasks

Comments

#1–Lydia Johnston: 04/16/2014 9:13 PM GMT

Action: **Create**

Artifact artf2541 : Run GearsBot Sample Code in Gazebo

Tracker:	Tasks
Title:	Run GearsBot Sample Code in Gazebo
Description:	This step involves successfully running the sample code for GearsBot in Gazebo. Tutorials for this task may be found under "Creating and Running a Project" at the link below: http://wpilib.screenstepslive.com Please post any questions or errors in the process or documentation to the Gazebo Questions discussion found at the link below: https://usfirst.collab.net/sf/discussion/do/listTopics/projects.wpilib_gazebo_simulator/discussion.gazebo_questions For guidelines on submitting errors, please see the thread on how to submit an error under the Updates and Resources discussion at the following link: https://usfirst.collab.net/sf/discussion/do/listPosts/projects.wpilib_gazebo_simulator/discussion.updates_and_resources. topc1142 When you have completed this step, please record your team number, completion status and any additional comments on this tracker.
Submitted By:	Lydia Johnston
Submitted On:	04/16/2014 9:15 PM GMT
Last Modified:	04/16/2014 9:15 PM GMT

Status / Comments

Status:*	Open
Category:*	All
Priority: *	4
Assigned To: *	Lydia Johnston
Planning Folder: *	None
Estimated Effort: *	0 Tasks
Remaining Effort: *	0 Tasks

Comments

#1–Lydia Johnston: 04/16/2014 9:15 PM GMT

Action: **Create**

Artifact artf2542 : Task 1: Behind the Box

Tracker:	Tasks
Title:	Task 1: Behind the Box
Description:	Change The autonomous section in the GearsBot code to have the robot deposit the can behind the box. This task is mostly designed to allow you to familiarize yourself with the program. A code walkthrough will be posted here: http://wpilib.screenstepslive.com You can post questions about this task here: https://usfirst.collab.net/sf/discussion/do/listPosts/projects.wpilib_gazebo_simulator/discussion.gazebo_questions.topc1151 When you have completed this step, please record your team number, completion status and any additional comments on this tracker.
Submitted By:	Lydia Johnston
Submitted On:	04/16/2014 9:16 PM GMT
Last Modified:	04/16/2014 9:16 PM GMT

Status / Comments

Status:*	Open
Category:*	All
Priority: *	4
Assigned To: *	Lydia Johnston
Planning Folder: *	None
Estimated Effort: *	0 Tasks
Remaining Effort: *	0 Tasks

Comments

#1–Lydia Johnston: 04/16/2014 9:16 PM GMT

Action: **Create**

Artifact artf2543 : Edit and Test GearsBot Sample Code

Tracker:	Tasks
Title:	Edit and Test GearsBot Sample Code
Description:	This intermediate step involves editing the GearsBot sample code. Topics for feedback include: - Issues or bug reports - Ease of process - Intuitiveness of interface and steps While you are completing this step, please post feedback to the Gazebo Questions discussion at the link below: https://usfirst.collab.net/sf/discussion/do/listTopics/projects.wpilib_gazebo_simulator/discussion.gazebo_questions When you have completed this step, please update the progress in this tracker and include your team number and any final comments.
Submitted By:	Lydia Johnston
Submitted On:	04/16/2014 9:17 PM GMT
Last Modified:	04/16/2014 9:17 PM GMT

Status / Comments

Status:*	Open
Category:*	All
Priority: *	4
Assigned To: *	Lydia Johnston
Planning Folder: *	None
Estimated Effort: *	0 Tasks
Remaining Effort: *	0 Tasks

Comments

#1–Lydia Johnston: 04/16/2014 9:17 PM GMT

Action: **Create**

A.3 Status Update Mid Competition Season

Default Question Block

This is a quick 4-question survey to gauge your progress so far with Gazebo.

What is your FRC team number?

Are you a student or a mentor?

- Student
- Mentor

Have you been using Gazebo?

- Yes
- No

Please write a small summary of your progress so far. Important discussion points include:
- Which tasks you have completed (e.g. installing Linux, installing Gazebo, running test code)
- How often you have been using Gazebo
- Any difficulties with installing or running the software

Why not?

Please explain what would help you use Gazebo more.

A.4 Granite State Survey

Granite State Regional Survey

Thank you for testing out the FRC Gazebo Simulator Beta. This survey will get your general information and ask some questions on what you just have done with Gazebo and would like to see in the future.

What is your FRC Team number?

What is your role on the team?

- Student
- Mentor

What is your primary position on your team:

- Programmer
- Electrician
- Mechanic
- CAD Designer
- Other

What type of Simulators have you used in the past (check all that apply)?

- None
- 5th Gear
- LabVIEW Simulator
- Other

Please describe your level of experience with Linux:

	No Experience	Little Experience	Basic Use	Proficient	Expert
	○	○	○	○	○

What type(s) of CAD Software does your team use (check all that apply)?

- None
- SolidWorks
- Autodesk Inventor
- PTC
- Other

What programming language does your team use?

- Java
- C++
- LabVIEW
- Other

Please rate how useful you would find the following simulation functions:

	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful
Autonomous Testing					
Teleoperated Testing					
Mechanical Testing (i.e. drive trains)					
PID Tuning					
Sensor Calibration					
Gameplay Strategy					
Vision Processing					
Other:					

Did you test out the simulator?

- Yes
- No

Please rate the following with 1 being very poor and 10 being very high:

	1	2	3	4	5	6	7	8	9	10
Gazebo simulator functionality (i.e. workability)										
Gazebo simulator usability (i.e. user-friendly)										
Gazebo simulator utility (i.e. usefulness)										

Would you use the simulator if made available to you?

- Yes
- No

When do you see yourself using the simulator most often?

- Off Season

- Build Season
- Competition Season

What would you use it for, and how often?

Why not?

What additional features would you like to see added to the Gazebo FRC Simulator?

A.5 Rhode Island Survey

Regional Survey

Thank you for testing out the FRC Gazebo Simulator Beta. This survey asks some questions about your experience with the Gazebo demonstration and what you would like to see in the future.

What is your FRC Team number?

What is your role on the team?

- ○ Student
- ○ Mentor

What is your primary position on your team?

- ○ Programmer
- ○ Electrician
- ○ Mechanic
- ○ CAD Designer
- ○ Other

What type of simulators have you used in the past? (check all that apply)

- ☐ None
- ☐ 5th Gear
- ☐ LabVIEW Simulator
- ☐ Other

Please describe your level of experience with Linux:

	No Experience	Little Experience	Basic Use	Proficient	Expert
	○	○	○	○	○

What type(s) of CAD Software does your team use (check all that apply)?

- ☐ None
- ☐ SolidWorks
- ☐ Autodesk Inventor
- ☐ PTC
- ☐ Other

What programming language does your team use (check all that apply)?

- Java
- C++
- LabVIEW
- Other

Please rate how useful you would find the following two styles of testing:

	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful
Using Gazebo to test your own imported models					
Using Gazebo to write and test code for pre-made game-related robots only					

Which best describes your team's process for designing your robot?

- Develop detailed design, attempt to build once and test
- Quickly develop a design, then iteratively build, test and redesign
- Prototype rough sketches immediately, then make modifications based on extensive testing until the final design is reached

Please rate how useful you would find the following simulation functions:

	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful
Autonomous Testing					
Teleoperated Testing					
Robot/Game Object Interaction					
Robot Prototyping					
Mechanical Testing (e.g. drive trains)					
PID Tuning					
Sensor Calibration					
Gameplay Strategy					
Vision Processing					

Are there any additional features you would like to see?

Did you test out the simulator?

- Yes
- No

Please rate the following with 1 being very poor and 10 being very high:

	1	2	2	3	4	5	6	7	8	9	10
Gazebo simulator functionality (i.e. workability)											
Gazebo simulator usability (i.e. user-friendly)											
Gazebo simulator utility (i.e. usefulness)											

Would you use the simulator if made available to you?

- Yes
- No

When do you see yourself using the simulator most often?

- Off Season
- Build Season
- Competition Season

What would you use it for, and how often?

Which integration of simulation and design would you prefer?

- Develop and test robot model directly within Gazebo and use a model editor plugin
- Develop robot model in CAD, then export and test model with Gazebo

Why not?

Would you like to participate in the FRC Gazebo Beta?

If you select "Yes" we will request your first and last name and email address in the next question. They will only be used to help create TeamForge accounts to grant access to the FRC Gazebo Beta files and tutorials.

- Yes

◯ No

Please fill out the following:

First Name

Last Name

Email Address

A.6 Post-Beta Survey

Post-Beta Survey

Thank you very much for your participation in the Gazebo Simulator Beta for FRC. This final set of questions is to assess your overall opinion of the Gazebo Simulator after having tested it to this point.

What is your FRC Team number?

What is your role on the team?

- Student
- Mentor

What is your primary position on your team:

- Programmer
- Electrician
- Mechanic
- CAD Designer
- Other

Which task trackers did you complete?

- Install Linux
- Install Gazebo and Related Problems
- Run GearsBot Sample Code in Gazebo
- Edit and Test GearsBot Sample Code
- Task 1: Behind the Box
- Did not complete any trackers

Please rate the following with 1 being very poor and 10 being very high:

	1	2	2	3	4	5	6	7	8	9	10
Gazebo simulator utility											
Gazebo simulator usability (i.e. user-friendly)											
Clarity of the documentation											
Complexity of installation											
Simulator performance (e.g. frame rate, time scale)											

Would you use the simulator in the future?

- Yes
- No

What would you use it for, and how often?

Why not?

What changes would make you use the simulator?

Based on the final weeks, how would you rate the following in terms of being ready to be distributed to all of FIRST?

	Not Ready at All	Barely Ready	Somewhat Ready	Almost Ready	Completely Ready
Gazebo Simulator					
Gazebo Simulator Documentation					
SolidWorks Model Importer					

Please state your reasoning:

What additional features would you like to see added to the Gazebo FRC Simulator?

Please rate the helpfulness of the support from the development team.

	Not helpful	Somewhat helpful	Extremely helpful	Did not use
Development Team Support				

At this stage of the Gazebo simulator and documentation, how could either the simulator or documentation be further improved for the next FRC season?

Please write your email address below if you wish to be in the raffle for a $50 Gift Card (your choice between Newegg, Amazon, or Barnes & Noble).

A.7 Post-Beta Questionnaire

Team #1

1) Did you have any Linux experience going into this beta? If so, how much experience?

Yes

2) Have you used Gazebo at all? If no, why not?

No

3) What would have made you use Gazebo more?

More time

4) Did you log into Teamforge during the course of the beta?

He did, downloaded the samples

4a) If yes, did you like TeamForge as a distribution method?

It was fine

5) What improvements or changes would you like to see to make it easier for you and other teams to use Gazebo?

Changing the version of linux

6) Realistically, do you think there is enough time to use Gazebo during build season, or by FIRST teams in general?

More useful during the offseason

6a) If not, what do you think would be more realistic for its use (i.e. what should Gazebo be used for)?

see above

7) Was the installation process a significant barrier to using Gazebo? If so, how?

yes, because of ubuntu version problems

Team #2

1) Did you have any Linux experience going into this beta? If so, how much experience?

Yes, a lot of experience

2) Have you used Gazebo at all? If no, why not?

Yes, drove in tele-op mode

3) What would have made you use Gazebo more?

Everything is in a perfect world, want to make it more world-like e.g. can stall the motors, something breaks

4) Did you log into Teamforge during the course of the beta?

Did not have time to use TeamForge

5) What improvements or changes would you like to see to make it easier for you and other teams to use Gazebo?

Pretty good and easy currently

6) Realistically, do you think there is enough time to use Gazebo during build season, or by FIRST teams in general?

Yes; if it was set up before build season it would be easy

6a) If not, what do you think would be more realistic for its use (i.e. what should Gazebo be used for)?

N/A

7) Was the installation process a significant barrier to using Gazebo? If so, how?

No

Team #3

1) Did you have any Linux experience going into this beta? If so, how much experience?

Moderate experience

2) Have you used Gazebo at all? If no, why not?

No, no time

3) What would have made you use Gazebo more?

Didn't know they had to use it this early (was planning on using it over the summer or in Fall)

4) Did you log into Teamforge during the course of the beta?

No; didn't realize they had to do the beta yet

5) What improvements or changes would you like to see to make it easier for you and other teams to use Gazebo?

No; just didn't have time

6) Realistically, do you think there is enough time to use Gazebo during build season, or by FIRST teams in general?

Would have time; would install before the build season and want to play with it off season

6a) If not, what do you think would be more realistic for its use (i.e. what should Gazebo be used for)?

N/A

7) Was the installation process a significant barrier to using Gazebo? If so, how?

Hasn't installed; it does seem like a barrier but having time to play with it before build season would help

Team #4

1) Did you have any Linux experience going into this beta? If so, how much experience?

No

2) Have you used Gazebo at all? If no, why not?

No, too busy

3) What would have made you use Gazebo more?

Different timing

4) Did you log into Teamforge during the course of the beta?

No

4a) If yes, did you like TeamForge as a distribution method?

N/A

5) What improvements or changes would you like to see to make it easier for you and other teams to use Gazebo?

N/A

6) Realistically, do you think there is enough time to use Gazebo during build season, or by FIRST teams in general?

N/A

6a) If not, what do you think would be more realistic for its use (i.e. what should Gazebo be used for)?

N/A

7) Was the installation process a significant barrier to using Gazebo? If so, how?

N/A

B Raw Survey Results Data

B.1 Regional Survey Data

B.1.1 Granite State District Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		7	88%
2	Mentor		1	13%
	Total		8	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		4	50%
2	Electrician		0	0%
3	Mechanic		2	25%
4	CAD Designer		1	13%
5	Other		1	13%
	Total		8	

What type of Simulators have you used in the past (check all that apply)?

#	Answer	Bar	Response	%
1	None		6	75%
2	5th Gear		0	0%
3	LabVIEW Simulator		1	13%
4	Other		2	25%

Please describe your level of experience with Linux.

#	Question	No Experience	Little Experience	Basic Use	Proficient	Expert	Total Responses	Mean
1		1	2	2	3	0	8	2.88

Statistic	
Min Value	1
Max Value	4
Mean	2.88
Variance	1.27
Standard Deviation	1.13
Total Responses	8

What type(s) of CAD Software does your team use (check all that apply)?

#	Answer	Bar	Response	%
1	None		4	50%
2	SolidWorks		2	25%
3	Autodesk Inventor		2	25%
4	PTC		2	25%
5	Other		0	0%

What programming language does your team use?

#	Answer	Bar	Response	%
1	Java		7	88%
2	C++		0	0%
3	LabVIEW		1	13%
4	Other		0	0%
	Total		8	

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		7	88%
2	Mentor		1	13%
	Total		8	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		4	50%
2	Electrician		0	0%
3	Mechanic		2	25%
4	CAD Designer		1	13%
5	Other		1	13%
	Total		8	

What type of Simulators have you used in the past (check all that apply)?

#	Answer	Bar	Response	%
1	None		6	75%
2	5th Gear		0	0%
3	LabVIEW Simulator		1	13%
4	Other		2	25%

Please describe your level of experience with Linux.

#	Question	No Experience	Little Experience	Basic Use	Proficient	Expert	Total Responses	Mean
1		1	2	2	3	0	8	2.88

Statistic	
Min Value	1
Max Value	4
Mean	2.88
Variance	1.27
Standard Deviation	1.13
Total Responses	8

What type(s) of CAD Software does your team use (check all that apply)?

#	Answer	Bar	Response	%
1	None		4	50%
2	SolidWorks		2	25%
3	Autodesk Inventor		2	25%
4	PTC		2	25%
5	Other		0	0%

What programming language does your team use?

#	Answer	Bar	Response	%
1	Java		7	88%
2	C++		0	0%
3	LabVIEW		1	13%
4	Other		0	0%
	Total		8	

B.1.2 Groton District Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		6	60%
2	Mentor		4	40%
	Total		10	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		5	50%
2	Electrician		2	20%
3	Mechanic		2	20%
4	CAD Designer		0	0%
5	Other		1	10%
	Total		10	

What type of Simulators have you used in the past (check all that apply)?

#	Answer	Bar	Response	%
1	None		8	89%
2	5th Gear		0	0%
3	LabVIEW Simulator		1	11%
4	Other		0	0%

Please describe your level of experience with Linux.

#	Question	No Experience	Little Experience	Basic Use	Proficient	Expert	Total Responses	Mean
1		2	3	0	1	3	9	3.00

Statistic	
Min Value	1
Max Value	5
Mean	3.00
Variance	3.00
Standard Deviation	1.73
Total Responses	9

What type(s) of CAD Software does your team use (check all that apply)?

#	Answer	Bar	Response	%
1	None		2	22%
2	SolidWorks		4	44%
3	Autodesk Inventor		4	44%
4	PTC		2	22%
5	Other		0	0%

What programming language does your team use?

#	Answer	Bar	Response	%
1	Java		5	56%
2	C++		1	11%
3	LabVIEW		2	22%
4	Other		1	11%
	Total		9	

Please rate how useful you would fund the following two styles of testing:

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Using Gazebo to test your own imported models	0	0	0	2	7	9	4.78
2	Using Gazebo to write and test code for pre-made game-related robots only	0	1	2	3	3	9	3.89

Statistic	Using Gazebo to test your own imported models	Using Gazebo to write and test code for pre-made game-related robots only
Min Value	4	2
Max Value	5	5
Mean	4.78	3.89
Variance	0.19	1.11
Standard Deviation	0.44	1.05
Total Responses	9	9

Which best describes your team's process for designing your robot?

#	Answer	Bar	Response	%
2	Develop detailed design, attempt to build once and test		4	44%
3	Quickly develop a design, then iteratively build, test and redesign		4	44%
4	Prototype rough sketches immediately, then make modifications based on extensive testing until the final design is reached		1	11%
	Total		9	

Please rate how useful you would find the following simulation function.

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Autonomous Testing	0	0	0	3	6	9	4.67
2	Teleoperated Testing	0	0	0	2	7	9	4.78
3	Mechanical Testing (e.g. drive trains)	0	2	1	4	2	9	3.67
4	PID Tuning	1	0	1	1	6	9	4.22
5	Sensor Calibration	1	1	1	3	3	9	3.67
6	Gameplay Strategy	1	0	1	3	4	9	4.00
7	Vision Processing	0	0	0	5	4	9	4.44
9	Robot/Game Object Interaction	0	0	1	3	5	9	4.44
16	Robot Prototyping	0	2	0	5	2	9	3.78

Statistic	Autonomous Testing	Teleoperated Testing	Mechanical Testing (e.g. drive trains)	PID Tuning	Sensor Calibration	Gameplay Strategy	Vision Processing	Robot/Game Object Interaction	Robot Prototyping
Min Value	4	4	2	1	1	1	4	3	2
Max Value	5	5	5	5	5	5	5	5	5
Mean	4.67	4.78	3.67	4.22	3.67	4.00	4.44	4.44	3.78
Variance	0.25	0.19	1.25	1.94	2.00	1.75	0.28	0.53	1.19
Standard Deviation	0.50	0.44	1.12	1.39	1.41	1.32	0.53	0.73	1.09
Total Responses	9	9	9	9	9	9	9	9	9

Are they any additional features you would like to see?

Text Response
A repository for community sourced components such as gearbox-motor combinations.

Did you test out the simulator?

#	Answer	Bar	Response	%
1	Yes		5	56%
2	No		4	44%
	Total		9	

Please rate the following with 1 being very poor and 10 being very high:

#	Question	1	2	2	3	4	5	6	7	8	9	10	Total Responses	Mean
1	Gazebo simulator functionality (i.e. workability)	0	0	0	0	0	0	0	0	1	2	2	5	10.20
2	Gazebo simulator usability (i.e. user-friendly)	0	0	0	0	0	0	2	0	0	2	1	5	9.00
3	Gazebo simulator utility (i.e. usefulness)	0	0	0	0	0	0	0	0	2	1	2	5	10.00

Statistic	Gazebo simulator functionality (i.e. workability)	Gazebo simulator usability (i.e. user-friendly)	Gazebo simulator utility (i.e. usefulness)
Min Value	9	7	9
Max Value	11	11	11
Mean	10.20	9.00	10.00
Variance	0.70	3.50	1.00
Standard Deviation	0.84	1.87	1.00
Total Responses	5	5	5

Would you use the simulator if made available to you?

#	Answer	Bar	Response	%
1	Yes		9	100%
2	No		0	0%
	Total		9	

When do you see yourself using the simulator most often?

#	Answer	Bar	Response	%
1	Off Season		2	22%
2	Build Season		7	78%
3	Competition Season		0	0%
	Total		9	

What would you use it for, and how often?

Text Response
Testing code whenever the coders finish their code.
Develop code for robot as it is being built.
program testing and design
Testing programming before build season when our test bot is not available for use
All day just testing.
As we are a rookie team it is difficult to envision exactly how we could use this, but I'd imagine that a wide variety of uses, in and out season.
Testing code after the robot was designed but is still being built, and forming team strategies in the brainstorming stage of build season.
To test robots
Training drivers, programmers, and build team members how to design, test and construct a robot and also integrate programmers, electrical and mechanical team members into the design process so that each group has a full understanding of the design parameters and functions of the robot before going into a full scale build process. Would use it continuously during build season and during robotics class instruction periods during the school year.

Which integration of simulation would you prefer?

#	Answer	Bar	Response	%
1	Develop and test robot model directly within Gazebo and use a model editor plugin		4	44%
2	Develop robot model in CAD, then export and test model with Gazebo		5	56%
	Total		9	

B.1.3 WPI District Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		5	42%
2	Mentor		7	58%
	Total		12	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		8	67%
2	Electrician		1	8%
3	Mechanic		1	8%
4	CAD Designer		0	0%
5	Other		2	17%
	Total		12	

What type of Simulators have you used in the past (check all that apply)?

#	Answer	Bar	Response	%
1	None		10	83%
2	5th Gear		0	0%
3	LabVIEW Simulator		2	17%
4	Other		0	0%

What type(s) of CAD Software does your team use (check all that apply)?

#	Answer	Bar	Response	%
1	None		1	8%
2	SolidWorks		8	67%
3	Autodesk Inventor		4	33%
4	PTC		0	0%
5	Other		1	8%

Please describe your level of experience with Linux.

#	Question	No Experience	Little Experience	Basic Use	Proficient	Expert	Total Responses	Mean
1		3	2	2	4	1	12	2.83

Please rate how useful you would find the following two styles of testing:

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Using Gazebo to test your own imported models	0	0	1	4	7	12	4.50
2	Using Gazebo to write and test code for pre-made game-related robots only	0	0	2	3	7	12	4.42

Statistic	Using Gazebo to test your own imported models	Using Gazebo to write and test code for pre-made game-related robots only
Min Value	3	3
Max Value	5	5
Mean	4.50	4.42
Variance	0.45	0.63
Standard Deviation	0.67	0.79
Total Responses	12	12

What programming language does your team use?

#	Answer	Bar	Response	%
1	Java		10	83%
2	C++		3	25%
3	LabVIEW		2	17%
4	Other		1	8%

Please rate how useful you would find the following simulation function.

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Autonomous Testing	0	0	1	3	8	12	4.58
2	Teleoperated Testing	0	0	1	6	5	12	4.33
3	Mechanical Testing (e.g. drive trains)	0	1	3	2	6	12	4.08
4	PID Tuning	0	0	2	2	8	12	4.50
5	Sensor Calibration	0	0	2	3	7	12	4.42
6	Gameplay Strategy	0	1	2	2	7	12	4.25
7	Vision Processing	2	1	1	3	5	12	3.67
9	Robot/Game Object Interaction	0	0	2	5	5	12	4.25
16	Robot Prototyping	0	0	2	5	5	12	4.25

Statistic	Autonomous Testing	Teleoperated Testing	Mechanical Testing (e.g. drive trains)	PID Tuning	Sensor Calibration	Gameplay Strategy	Vision Processing	Robot/Game Object Interaction	Robot Prototyping
Min Value	3	3	2	3	3	2	1	3	3
Max Value	5	5	5	5	5	5	5	5	5
Mean	4.58	4.33	4.08	4.50	4.42	4.25	3.67	4.25	4.25
Variance	0.45	0.42	1.17	0.64	0.63	1.11	2.42	0.57	0.57
Standard Deviation	0.67	0.65	1.08	0.80	0.79	1.06	1.56	0.75	0.75
Total Responses	12	12	12	12	12	12	12	12	12

Did you test out the simulator?

#	Answer	Bar	Response	%
1	Yes		10	83%
2	No		2	17%
	Total		12	

Please rate the following with 1 being very poor and 10 being very high:

#	Question	1	2	2	3	4	5	6	7	8	9	10	Total Responses	Mean
1	Gazebo simulator functionality (i.e. workability)	0	0	0	0	0	0	2	1	2	2	3	10	9.30
2	Gazebo simulator usability (i.e. user-friendly)	0	0	0	0	0	0	1	3	1	2	3	10	9.30
3	Gazebo simulator utility (i.e. usefulness)	0	0	0	0	0	0	0	2	1	3	4	10	9.90

Statistic	Gazebo simulator functionality (i.e. workability)	Gazebo simulator usability (i.e. user-friendly)	Gazebo simulator utility (i.e. usefulness)
Min Value	7	7	8
Max Value	11	11	11
Mean	9.30	9.30	9.90
Variance	2.46	2.23	1.43
Standard Deviation	1.57	1.49	1.20
Total Responses	10	10	10

Would you use the simulator if made available to you?

#	Answer	Bar	Response	%
1	Yes		12	100%
2	No		0	0%
	Total		12	

When do you see yourself using the simulator most often?

#	Answer	Bar	Response	%
1	Off Season		2	17%
2	Build Season		9	75%
3	Competition Season		1	8%
	Total		12	

What would you use it for, and how often?

Text Response
test designs test prototypes often
to test robots while the final comp bot will be completed
0
.
teaching programming demoing designs
testing
I would use it, if we got it to work, before the robot was finished to test the code. HOWEVER we might not be able to use it very often; I know I just said yes to "would I use it if provided" but we don't have a ton of time to dedicate to it.
testing/building code
Training new drivers and testing autonomous coe
As a programmer, I'd use it for debugging and also testing new features in the code.
Testing code, and prototyping
testing the robot before competiton for functionality

Which best describers your team's process for designing your robot?

#	Answer	Bar	Response	%
2	Develop detailed design, attempt to build once and test		5	42%
3	Quickly develop a design, then iteratively build, test and redesign		2	17%
4	Prototype rough sketches immediately, then make modifications based on extensive testing until the final design is reached		5	42%
	Total		12	

What additional features would you like to see added to the Gazebo FRC simulator?

Text Response
LAN parties, essentially simulating a match but with human players on each robot.

Which integration of simulation and design would you prefer?

#	Answer	Bar	Response	%
1	Develop and test robot model directly within Gazebo and use a model editor plugin		1	8%
2	Develop robot model in CAD, then export and test model with Gazebo		11	92%
	Total		12	

B.1.4 Rhode Island Regional Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		28	70%
2	Mentor		12	30%
	Total		40	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		8	20%
2	Electrician		4	10%
3	Mechanic		14	35%
4	CAD Designer		1	3%
5	Other		13	33%
	Total		40	

What type of Simulators have you used in the past (check all that apply)?

#	Answer	Bar	Response	%
1	None		29	73%
2	5th Gear		1	3%
3	LabVIEW Simulator		9	23%
4	Other		2	5%

Other
CAD
Blender

Please describe your level of experience with Linux.

#	Question	No Experience	Little Experience	Basic Use	Proficient	Expert	Total Responses	Mean
1		13	8	10	7	2	40	2.43

Statistic	
Min Value	1
Max Value	5
Mean	2.43
Variance	1.58
Standard Deviation	1.26
Total Responses	40

What type(s) of CAD Software does your team use (check all that apply)?*

#	Answer	Bar	Response	%
1	None		10	25%
2	SolidWorks		19	48%
3	Autodesk Inventor		5	13%
4	PTC		3	8%
5	Other		6	15%

* This shows individual responses and doesn't reflect unique teams, as is noted in Section 4.1.4

What programming language does your team use?[†]

#	Answer	Bar	Response	%
1	Java		31	78%
2	C++		6	15%
3	LabVIEW		14	35%
4	Other		1	3%

Please rate how useful you would find the following two styles of testing:

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Using Gazebo to test your own imported models	1	1	10	11	17	40	4.05
2	Using Gazebo to write and test code for pre-made game-related robots only	0	2	18	10	10	40	3.70

Statistic	Using Gazebo to test your own imported models	Using Gazebo to write and test code for pre-made game-related robots only
Min Value	1	2
Max Value	5	5
Mean	4.05	3.70
Variance	1.02	0.83
Standard Deviation	1.01	0.91
Total Responses	40	40

Which best describes your team's process for designing your robot?[‡]

#	Answer	Bar	Response	%
2	Develop detailed design, attempt to build once and test		14	35%
3	Quickly develop a design, then iteratively build, test and redesign		15	38%
4	Prototype rough sketches immediately, then make modifications based on extensive testing until the final design is reached		11	28%
	Total		40	

Please rate how useful you would find the following simulation function.

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Autonomous Testing	0	1	12	12	15	40	4.03
2	Teleoperated Testing	0	2	9	14	15	40	4.05
3	Mechanical Testing (e.g. drive trains)	0	2	12	15	11	40	3.88
4	PID Tuning	0	5	17	11	7	40	3.50
5	Sensor Calibration	1	4	18	7	10	40	3.53
6	Gameplay Strategy	0	5	11	14	10	40	3.73
7	Vision Processing	0	8	12	10	10	40	3.55
9	Robot/Game Object Interaction	0	2	7	23	8	40	3.93
16	Robot Prototyping	0	1	11	17	11	40	3.95

Statistic	Autonomous Testing	Teleoperated Testing	Mechanical Testing (e.g. drive trains)	PID Tuning	Sensor Calibration	Gameplay Strategy	Vision Processing	Robot/Game Object Interaction	Robot Prototyping
Min Value	2	2	2	2	1	2	2	2	2
Max Value	5	5	5	5	5	5	5	5	5
Mean	4.03	4.05	3.88	3.50	3.53	3.73	3.55	3.93	3.95
Variance	0.79	0.82	0.78	0.87	1.13	0.97	1.18	0.58	0.66
Standard Deviation	0.89	0.90	0.88	0.93	1.06	0.99	1.08	0.76	0.81
Total Responses	40	40	40	40	40	40	40	40	40

[†] This shows individual responses and doesn't reflect unique teams, as is noted in Section 4.1.4
[‡] This shows individual responses and doesn't reflect unique teams, as is noted in Section 4.1.4

Are there any additional features you would like to see?

Text Response
being able to use logitech attack 3 joysticks+ xbox controller
good/tunable wheel friction model
Fast help resource
Nope
N/A
no
BLINCOLN!!
None
no

Did you test out the simulator?

#	Answer	Bar	Response	%
1	Yes		33	83%
2	No		7	18%
	Total		40	

Please rate the following with 1 being very poor and 10 being very high:

#	Question	1	2	2	3	4	5	6	7	8	9	10	Total Responses	Mean
1	Gazebo simulator functionality (i.e. workability)	0	1	0	0	0	2	1	7	12	5	5	33	8.79
2	Gazebo simulator usability (i.e. user-friendly)	0	1	1	0	0	3	5	4	9	5	5	33	8.36
3	Gazebo simulator utility (i.e. usefulness)	0	1	0	0	0	2	1	6	4	11	8	33	9.18

Statistic	Gazebo simulator functionality (i.e. workability)	Gazebo simulator usability (i.e. user-friendly)	Gazebo simulator utility (i.e. usefulness)
Min Value	2	2	2
Max Value	11	11	11
Mean	8.79	8.36	9.18
Variance	3.17	4.61	3.72
Standard Deviation	1.78	2.15	1.93
Total Responses	33	33	33

Would you use the simulator if made available to you?

#	Answer	Bar	Response	%
1	Yes		40	100%
2	No		0	0%
	Total		40	

When do you see yourself using the simulator most often?

#	Answer	Bar	Response	%
1	Off Season		3	8%
2	Build Season		36	90%
3	Competition Season		1	3%
	Total		40	

What would you use it for, and how often?

Text Response
Design process, essentially testing the robot before it has been built.
testing design before building them
We would use it to test code w/o having to take the robot away from the mechanical team or wait for them to finish a part. We may also use it for basic driver training (VR goggles like Oculus Rift running this would be cool). We would probably also use it for testing prototypes.
To see if the robot is functional with the current design.
when biulding the robot
To design and test the robot right after we get the challenge.
I would use it for software testing, because the software team doesnt have access to the robot as much as the build team, and they dont get to test out their code until the later weeks. This would help a lot in getting the code working before the competition
during build season
software training, software development, initial mechanical modeling
program robot for first
Self training, scenario development, demo to others, rookie training
Prototyping and testing design functions, before building the final robot.
Use it to test
testing fully CADded designs
To test out autonomous, and to develop game strategies.
Testing mechanical and programs.
designing a robot
test drive, strategy
Programming the robot
allow new students learn to program with out having a robot
i would use it for tests on the robot for multiple situations
Testing code
Testing prototypes
To test designs without building them.
testing programming and driving
I would use it to play around, and get used to how my robot works.
ask at teaching tool
To test coding and manipulator design
I think we would use it very often, and it might force us to get more complete CAD designs. It would allow us to test earlier, and have drivers practice sooner.
To get a visually compelling argument
testing our prototype
Testing st the start of a season
Testing robot designs
I would use it to test code changes when to robot is not fully built, or having modifications made which prohibit testing the changes.
Designing and building the robot for almost all of build season
Testing to see if the robot could pick stuff up etc.
Testing robots.
during building for enhanceing your skill
to test designs often
developing software prior to robot completion

Which integration of simulation and design would you prefer?

#	Answer	Bar	Response	%
1	Develop and test robot model directly within Gazebo and use a model editor plugin		15	38%
2	Develop robot model in CAD, then export and test model with Gazebo		25	63%
	Total		40	

B.2 Beta Survey Data

B.2.1 Pre-Beta Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		5	38%
2	Mentor		8	62%
	Total		13	

Have you used a robotics simulator in the past?

#	Answer	Bar	Response	%
1	Yes		3	23%
2	No		10	77%
	Total		13	

What robotic simulators have you used?

#	Answer	Bar	Response	%
1	5th Gear		1	50%
2	LabVIEW Simulator		1	50%
3	Other:		1	50%

Other:
Our own - https://github.com/itsZN/FRC-Robot-Emulator

Please describe your level of experience with Linux:

#	Question	No Experience	Little experience	Basic use	Proficient	Expert	Total Responses	Mean
1		2	0	3	3	4	12	3.58

Statistic	
Min Value	1
Max Value	5
Mean	3.58
Variance	2.08
Standard Deviation	1.44
Total Responses	12

Have you used Ubuntu before?

#	Answer	Bar	Response	%
1	Yes		10	100%
2	No		0	0%
	Total		10	

Would your school give you permissions to install Ubuntu, a Linux-based computer operating system on a computer your team has access to during build season?

#	Answer	Bar	Response	%
1	Yes		11	92%
2	No		1	8%
	Total		12	

Please list the CPU (Central Processing Unit) of the computer you would install Gazebo on:

Text Response
Intel Core(tm) i7-3630QM
Intel i5-4770K
AMD Athalon II X4 635 (Two cores allocated via virtual machine)
i5
Core i7-3930K CPU @ 3.2GHZ 64G Memory
Fast enough - Core i3 or above
i7 3770K
Depends. We'd probably set up a virtual server.
Intel Core i7 4 core 2.2 GHz
Intel Core i5-4200U

Please list the GPU (Graphics Processing Unit) of the computer you would install Gazebo on:

Text Response
NVIDIA GeForce GT 635M
NVIDIA GTX 480
AMD Radeon HD 5570 (Via virtual machine)
not known
GeForce GTX 680
Fast enough
Nvidia GTX680
Virtual server.
AMD Radeon HD 6750M and/or Intel HD Graphics 3000
Integrated Graphics

Do you have at least 10 GB of free hard drive space?

#	Answer	Bar	Response	%
1	Yes		10	100%
2	No		0	0%
	Total		10	

Please rate how useful you would find the following simulation functions:§

#	Question	Not Useful	Rarely Useful	Somewhat Useful	Useful	Very Useful	Total Responses	Mean
1	Autonomous Testing	0	0	1	3	6	10	4.50
2	Teleoperated Testing	0	1	0	4	5	10	4.30
3	Mechanical Testing (i.e. drive trains)	0	1	5	3	1	10	3.40
4	PID Tuning	0	0	4	4	2	10	3.80
5	Sensor Calibration	0	1	4	3	2	10	3.60
6	Gameplay Strategy	0	1	1	5	3	10	4.00
7	Vision Processing	1	0	3	2	4	10	3.80
8	Other:	4	0	0	2	4	10	3.20

Other:
Testing code sans robot
Electronic Wiring Testing
Command Testing
Mechanical (but not drive train)
n/a
Whatever comes up

Statistic	Autonomous Testing	Teleoperated Testing	Mechanical Testing (i.e. drive trains)	PID Tuning	Sensor Calibration	Gameplay Strategy	Vision Processing	Other:
Min Value	3	2	2	3	2	2	1	1
Max Value	5	5	5	5	5	5	5	5
Mean	4.50	4.30	3.40	3.80	3.60	4.00	3.80	3.20
Variance	0.50	0.90	0.71	0.62	0.93	0.89	1.73	3.73
Standard Deviation	0.71	0.95	0.84	0.79	0.97	0.94	1.32	1.93
Total Responses	10	10	10	10	10	10	10	10

Do you use CAD software?

#	Answer	Bar	Response	%
1	Yes		8	80%
2	No		2	20%
	Total		10	

What types of CAD Software do you use (select all that apply)?

#	Answer	Bar	Response	%
1	SolidWorks		5	63%
2	Autodesk Inventor		5	63%
3	PTC		1	13%
4	Other:		1	13%

Other:
Rhino

§ "Other" refers to additional features beta teams would like to see, and its statistical value can be ignored

What do you use SolidWorks for (check all that apply)?

#	Answer	Bar	Response	%
1	Manufacturing (e.g. laser cutting, 3-D printing, water jetting)		4	80%
2	To design a virtual robot to show to sponsors		2	40%
3	To design a virtual robot to show to other teams and judges at competition		3	60%
4	To animate a virtual robot or certain aspect of the robot such as its drive train		3	60%
5	Other:		2	40%

Other:
To design the robot
Still learning

Which features of SolidWorks does your CAD team lead know about and use (check all that apply)?

#	Answer	Bar	Response	%
1	Setting axis points on joints		5	100%
2	"Shrink wrapping" parts		2	40%
3	Exporting to a URDF file		3	60%
4	Setting mass properties		3	60%
5	Setting inertial properties		2	40%
6	Setting material properties		3	60%

B.2.2 During-Beta Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		3	50%
2	Mentor		3	50%
	Total		6	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		4	67%
2	Electrical		2	33%
3	Mechanical		0	0%
4	CAD Designer		0	0%
5	Other		0	0%
	Total		6	

How many hours have you used Gazebo during build season?

#	Answer	Bar	Response	%
1	0 hrs		0	0%
2	1-3 hrs		3	50%
3	4-6 hrs		3	50%
4	7-9 hrs		0	0%
5	10+ hrs		0	0%
	Total		6	

What did you spend the MOST time doing?

#	Answer	Bar	Response	%
1	Installing/troubleshooting the software		3	60%
2	Looking up documentation		1	20%
3	Coding and simulating the robot		1	20%
	Total		5	

How did you use Gazebo during build season (check all that apply)?

#	Answer	Bar	Response	%
1	Did not code or simulate		3	75%
2	PID Tuning		0	0%
3	Autonomous simulation		0	0%
4	Teleoperated simulation		1	25%
5	Simulating drive train		0	0%
6	Sensor calibration		0	0%
7	Simulating manipulators (write in type of manipulator, e.g. arm, elevator)		0	0%
8	Other:		0	0%
9	Gameplay Strategy		0	0%
10	Robot Control		0	0%

How would you rate the functionality of the simulator with what you did?

#	Question	Did not work at all	Rarely worked	Somewhat worked	Usually worked	Worked perfectly	Total Responses	Mean
1	PID Tuning	0	0	0	0	0	0	0.00
2	Autonomous simulation	0	0	0	0	0	0	0.00
3	Teleoperated simulation	0	0	0	1	0	1	4.00
4	Sensor calibration	0	0	0	0	0	0	0.00
5	Simulating manipulators	0	0	0	0	0	0	0.00
6	Simulating drive train	0	0	0	0	0	0	0.00
7	Gameplay Strategy	0	0	0	0	0	0	0.00

How would you rate the usability of the simulator with what you did (i.e. was it user-friendly)?

#	Question	Was very hard to use	Was hard to use	Was somewhat hard to use	Neutral	Was somewhat easy to use	Was easy to use	Was very easy to use	Total Responses	Mean
1	PID Tuning	0	0	0	0	0	0	0	0	0.00
2	Autonomous simulation	0	0	0	0	0	0	0	0	0.00
3	Teleoperated simulation	0	0	1	0	0	0	0	1	3.00
4	Sensor calibration	0	0	0	0	0	0	0	0	0.00
5	Simulating manipulators	0	0	0	0	0	0	0	0	0.00
6	Simulating drive train	0	0	0	0	0	0	0	0	0.00
7	Gameplay Strategy	0	0	0	0	0	0	0	0	0.00

How would you rate the utility of the simulator with what you did (i.e. how much did the simulator help you in relation to your actual FRC robot)?

#	Question	Entirely ineffective	Ineffective	Somewhat effective	Effective	Very effective	Total Responses	Mean
1	PID Tuning	0	0	0	0	0	0	0.00
2	Autonomous simulation	0	0	0	0	0	0	0.00
3	Teleoperated simulation	0	0	1	0	0	1	3.00
4	Sensor calibration	0	0	0	0	0	0	0.00
5	Simulating manipulators	0	0	0	0	0	0	0.00
6	Simulating drive train	0	0	0	0	0	0	0.00
7	Gameplay Strategy	0	0	0	0	0	0	0.00

What is your favorite feature(s) of Gazebo? Why?

Text Response
The simulation runs well.

What is the most difficult part of Gazebo to use? Why?

Text Response
We had difficulties exporting our own robot into the simulation because we didn't have a 64bit windows computer to run the solidworks plugin on.

What is the most difficult part of Gazebo to understand? Why?

Text Response
The installation process was a bit convoluted.

Did you look at any of the documentation (i.e. the ScreenSteps user guide) this week for assistance?

#	Answer	Bar	Response	%
1	Yes		2	50%
2	No		2	50%
	Total		4	

What sections did you look at (check all that apply)?

#	Answer	Bar	Response	%
1	Getting Ubuntu 13.04 (Linux)		2	100%
2	After the Ubuntu Installation		2	100%
3	Running the Provided Examples		1	50%
4	Compiling for Simulation		1	50%

Was the documentation clear?

#	Question	Was not clear at all	Was somewhat clear	Was very clear and straightforward	Total Responses	Mean
1	Getting Ubuntu 13.04 (Linux)	0	1	1	2	2.50
2	After the Ubuntu Installation	0	0	2	2	3.00
3	Running the Provided Examples	0	0	1	1	3.00
4	Compiling for Simulation	0	0	1	1	3.00

Statistic	Getting Ubuntu 13.04 (Linux)	After the Ubuntu Installation	Running the Provided Examples	Compiling for Simulation
Min Value	2	3	3	3
Max Value	3	3	3	3
Mean	2.50	3.00	3.00	3.00
Variance	0.50	0.00	0.00	0.00
Standard Deviation	0.71	0.00	0.00	0.00
Total Responses	2	2	1	1

Did you look outside the documentation for additional assistance?

#	Answer	Bar	Response	%
1	Yes		2	50%
2	No		2	50%
	Total		4	

Please describe what you searched for and where you found helpful support.

Text Response
Had issues installing Ubuntu on Haswell (Intel 4th Gen) i5 processor with Z87 Chipset and Raid5 Drive Array. Still in process of fully resolving. Support through various tech forums.
1

How does the software or documentation need to be improved (check all that apply)?

#	Answer	Bar	Response	%
1	Gazebo needs to have more functionality		1	25%
2	Gazebo needs to be more user-friendly		1	25%
3	The documentation needs to be cleaned up/understood more easily		0	0%
4	Nothing needs improvement		1	25%
5	Other		2	50%

Other
I am currently unable to use Gazebo with much of our code because I keep getting ClassNotDefined Errors with things from the WPI library
Still in process of debugging

Please rate the helpfulness of the support from the development team.

#	Question	Not helpful	Somewhat helpful	Extremely helpful	Did not use	Total Responses	Mean
1	Development Team Support	0	1	1	2	4	3.25

Additional Comments:

Text Response
I think that once this is a little more usable with the WPI libraries, it will be an excellent tool for helping to train programmers and for working with the robot before/after build season.
Still working on getting Ubuntu to work well with above listed hardware.
We've done minimal testing so far. We've had snow days and other challenges which have prevented us from fully testing. Things are beginning to loosen up so we will donate more time to the beta in the very near future.
n

B.2.3 Post-Beta Results

What is your role on the team?

#	Answer	Bar	Response	%
1	Student		4	57%
2	Mentor		3	43%
	Total		7	

What is your primary position on your team?

#	Answer	Bar	Response	%
1	Programmer		6	86%
2	Electrician		0	0%
3	Mechanic		1	14%
4	CAD Designer		0	0%
5	Other		0	0%
	Total		7	

Which task trackers did you complete?

#	Answer	Bar	Response	%
1	Install Linux		5	71%
2	Install Gazebo and Related Problems		3	43%
3	Run GearsBot Sample Code in Gazebo		3	43%
4	Edit and Test GearsBot Sample Code		1	14%
5	Task 1: Behind the Box		0	0%
6	Did not complete any trackers		2	29%

Please rate the following with 1 being very poor and 10 being very high:**

#	Question	1	2	2	3	4	5	6	7	8	9	10	Total Responses	Mean
1	Gazebo simulator utility	0	0	0	0	0	0	1	0	1	1	0	3	8.67
2	Gazebo simulator usability (i.e. user-friendly)	0	0	0	0	0	0	2	0	1	0	0	3	7.67
3	Clarity of the documentation	0	0	0	0	1	0	0	1	0	0	1	3	8.00
4	Complexity of installation	0	0	0	0	0	1	0	1	0	1	0	3	8.00
5	Simulator performance (e.g. frame rate, time scale)	0	0	0	0	0	1	0	1	0	1	0	3	8.00

Statistic	Gazebo simulator utility	Gazebo simulator usability (i.e. user-friendly)	Clarity of the documentation	Complexity of installation	Simulator performance (e.g. frame rate, time scale)
Min Value	7	7	5	6	6
Max Value	10	9	11	10	10
Mean	8.67	7.67	8.00	8.00	8.00
Variance	2.33	1.33	9.00	4.00	4.00
Standard Deviation	1.53	1.15	3.00	2.00	2.00
Total Responses	3	3	3	3	3

** Based on the 3 respondents that completed trackers beyond installing Linux

Would you use the simulator in the future?

#	Answer	Bar	Response	%
1	Yes		6	86%
2	No		1	14%
	Total		7	

---> If yes, what would you use it for, and how often?

Text Response
Testing robot designs and code functionality. During build to highlight robot functionality, during competition season to test tweaked software to verify code.
Early testing of software, early visualization of the mechanical design relative to the field, basically part of the design process.
Due to other obligations, I wasn't able do do much with Gazebo, but over the summer I hope to look into it more.
Testing
I would use it to test code changes when the robot is unavailable due to hardware modifications being made. This would happen quite often.
I would use the simulator to test robot functionality and assist in the design process. I would use it more than 2-3 times a week.

---> If no, why not?

Text Response
I had issues with being unable to use certain classes when I modified the GearsBot sample to use an XBox controller because I didn't have a joystick on hand; and there are a number of classes specific to Gazebo such as the Potentiometer class which would require changes to the final code I have/have generated from RobotBuilder in order to be usable with Gazebo, and I don't know that it's helpful enough to be worth that effort because I haven't been able to use it much.

---> If no, what changes would make you use the simulator?

Text Response
Usable on Windows, Driver Station program closer to competition program, usable with SmartDashboard(Didn't appear to be) and Robot Preferences

Based on the final weeks, how would you rate the following in terms of being ready to be distributed to all of *FIRST*?[††]*

#	Question	Not Ready at All	Barely Ready	Somewhat Ready	Almost Ready	Completely Ready	Total Responses	Mean
1	Gazebo Simulator	0	0	0	2	1	3	4.33
2	Gazebo Simulator Documentation	0	0	0	3	0	3	4.00
3	SolidWorks Model Importer	1	0	1	0	1	3	3.00

Statistic	Gazebo Simulator	Gazebo Simulator Documentation	SolidWorks Model Importer
Min Value	4	4	1
Max Value	5	4	5
Mean	4.33	4.00	3.00
Variance	0.33	0.00	4.00
Standard Deviation	0.58	0.00	2.00
Total Responses	3	3	3

Please state you reasoning:

Text Response
I haven't been able to use the program in recent weeks because I've been busy, but what I did use seemed a little bit more complicated to set up than the average person would be able to do easily; however, I would guess the program would be used more by team programmers, and they should have a better understanding of general computer systems. I have no idea about the Model Importer as I never had a chance to use it
Things are working fairly well and are fairly well documented, but model conversion is a bit more involved.
I feel that the documentation was a little "blocky" when reading it. It wasn't always clear at times what I should be doing and how to get to that point.

[††] Based on the 3 respondents that completed trackers beyond installing Linux

What additional features would you like to see added to the Gazebo FRC Simulator?

Text Response
Unknown
I would like to see more support for non-Netbeans development environments if possible.
Support for Windows.
I can't think of much. It's already pretty good for FRC testing purposes.

Please rate the helpfulness of the support from the development team:

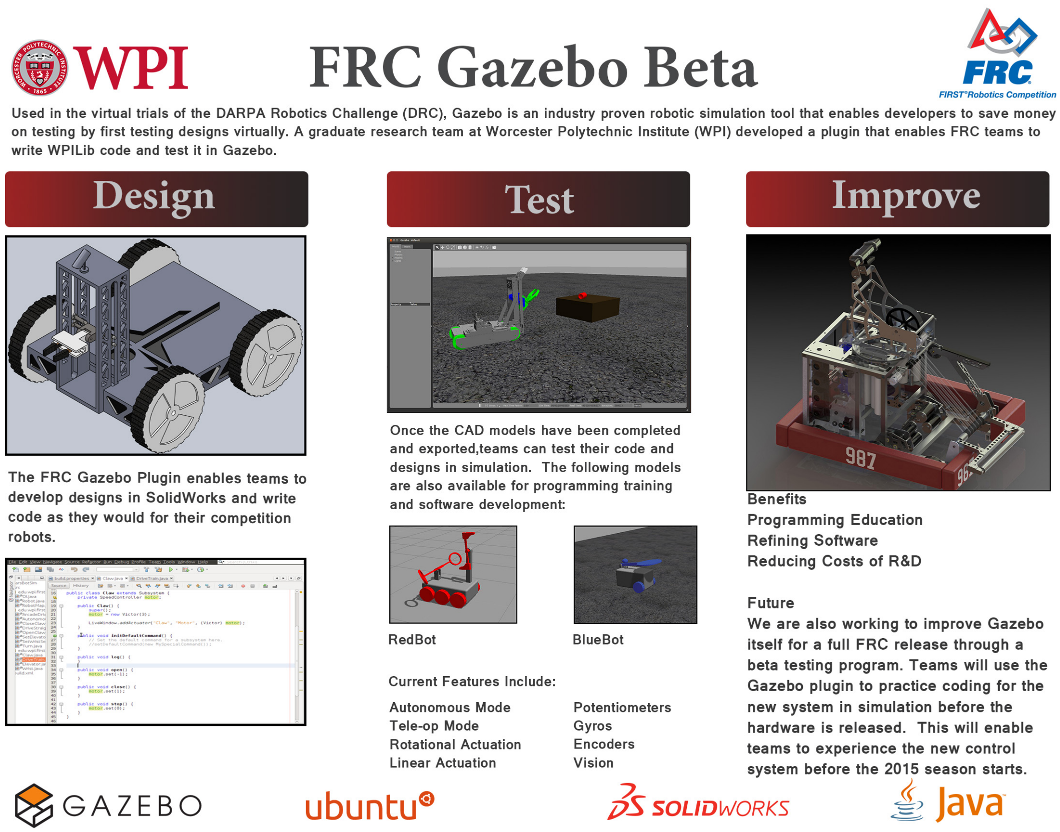
#	Question	Not helpful	Somewhat helpful	Extremely helpful	Did not use	Total Responses	Mean
1	Development Team Support	0	0	4	3	7	3.43

At this stage of the Gazebo simulator and documentation, how could either the simulator or documentation be further improves for the next FRC season.

Text Response
Unknown
A bit more information on hardware requirements would be helpful.
Support for Windows (and eventually Mac) would be a great improvement as would C++ support.
I believe the simulator is already fairly good to go in its current iteration. The documentation should be streamlined to ensure it's well understood (although it may very well be me who just wasn't reading it correctly.

C Images

C.1 Demonstration Poster



D Code

D.1 Ubuntu 13.10 Installation Script

```
#INSTALL BEGIN:
#Install random dependencies
sudo apt-get install lib32z1 lib32ncurses5 lib32bz2-1.0
#Install Gazebo
sudo sh -c ‘echo "deb http://packages.osrfoundation.org/gazebo/ubuntu saucy main"
> /etc/apt/sources.list.d/gazebo-latest.list’
wget http://packages.osrfoundation.org/gazebo.key -O - | sudo apt-key add -
sudo apt-get update
```

```
sudo apt-get install gazebo-current
#Install ROS (From Source)
sudo sh -c ‘echo "deb http://packages.ros.org/ros/ubuntu raring main" > /etc/apt/sources.list.d
wget http://packages.ros.org/ros.key -O - | sudo apt-key add -
sudo apt-get update
sudo apt-get install python-rosdep python-rosinstall-generator python-wstool python-rosinstall
build-essential
sudo rosdep init
rosdep update
mkdir ~/ros_catkin_ws
cd ~/ros_catkin_ws
rosinstall_generator desktop_full --rosdistro hydro --deps --wet-only -tar > hydro-desktop-full-
wstool init -j8 src hydro-desktop-full-wet.rosinstall
rosdep install --from-paths src --ignore-src --rosdistro hydro -y
./src/catkin/bin/catkin_make_isolated --install -DCMAKE_BUILD_TYPE=Release
sudo sh -c ‘echo "deb http://packages.osrfoundation.org/gazebo/ubuntu saucy main"
> /etc/apt/sources.list.d/gazebo-latest.list’
#Finalize Installation
# Setup the Enviroment variables
echo ‘Adding Envrioment Variables to your .bashrc’
echo ‘’ >> ~/.bashrc
echo ‘# Begin FRC simulation Enviroment Variables’ >> ~/.bashrc
echo ‘’ >> ~/.
echo ‘source $HOME/ros_catkin_ws/install_isolated/setup.bash’ >> ~/.bashrc
echo ‘export GAZEBO_PLUGIN_PATH=$GAZEBO_PLUGIN_PATH:$HOME/sunspotfrcsdk/sim/plugin’
>> ~/.bashrc
echo ‘LD_LIBRARY_PATH=$HOME/sunspotfrcsdk/sim/plugin:$HOME/sunspotfrcsdk/sim/lib:$LD_LIBRARY_PAT
>> ~/.bashrc
echo ‘export GAZEBO_MODEL_PATH=$GAZEBO_MODEL_PATH:$HOME/FRCSimModels’ >> ~/.bashrc
echo ‘’ >> ~/.bashrc
echo ‘# End FRC simulation Enviroment Variables ’ >> ~/.bashrc
```

```
# Add the models folder if it does not already exist
if [ !  -d "$HOME/FRCSimModels" ]; then
 mkdir ~/FRCSimModels
fi
```

E List of Abbreviations

CAD: Computer-Aided Design

DARPA: Defense Advanced Research Projects Agency

DRC: DARPA Robotics Challenge

***FIRST*:** For Inspiration and Recognition of Science and Technology

FRC: *FIRST* Robotics Competition

IQP: Interactive Qualifying Project

OSRF: Open Source Robotics Foundation

ROS: Robot Operating System

SD: Standard Deviation

STEM: Science, Technology, Engineering and Math

URDF: Unified Robot Description Format

VRC: Virtual Robotics Challenge

XML: Extensible Markup Language