Prototyping 101

Before building a complete product, mechanisms, designs, even gameplay need to be tried and tested. Prototyping is the act of creating preliminary mock-ups to verify the performance and test the feasibility of ideas.

Level 0: Prototyping Concepts

Robots start with a strategy for how to play the game. The next step is to answer the question of 'how'. Prototyping will allow your team to test your ideas and benchmark them against your predicted strategy.

1. ***Purpose of the Prototype***
    a. Each prototype should have specific goals in mind, derived from your overall robot strategy. The test cases for the prototype should help identify how this prototype meets the goal - how effectively this mechanism or play style meet the requirements created by the team during your strategy session.
        i. Check out this lengthy Behind the Lines video from 2015: Behind The Lines S02E03 - Effective Prototyping
2. ***What Should We Prototype?***
    a. The most important items to prototype are those that directly interact with the game objects or field elements. These change every year, and they are crucial to interact with to have a successful season.
    b. Some items, such as chassis' or gearboxes, should be designed based on past year's experiences as much as possible, and hopefully will not require prototyping. This allows you to focus your prototyping time and resources on new things, where they are needed most.
3. ***Testing the Prototype***
    a. The primary goal of prototyping is to test, record results, and improve the concept. Effective use of prototyping requires both iteration on the concept, and running and recording appropriate tests.
    b. For all tests that you run against your prototype, make sure you can record meaningful, preferably numeric, data. This data should align with the requirements of the mechanism as defined by your game strategy.
    c. Test your prototypes as if it were a real match. Make sure your drivers or operators are given realistic times, distances, and visibility, like they would in a real match.
    d. Each time you make a single change or tweak, re-run all meaningful tests. It is possible that the change renders some test moot. It is also possible that changing an item creates an unexpected behaviour in another item. Running every test after any change prevents regressions from occurring.
    e. Data collection and data analysis will show you what you ask for. Asking meaningful questions and creating meaningful tests will ensure that your

prototype is being used effectively, and providing the data that you need. Just because a prototype performs one action one time, does not make it perfect.

Level 1: Building the Prototype

Once you have a robot requirement and a general concept to build and test, it's time to put the gloves on and build it! The focus should be on building and changing things quickly AND recording the changes. The concept will evolve through this process.

1. ***Make a Simple Version***
    a. Ideas formed in your head need to be communicated to others. Start with sketches on paper, whiteboard, or simple shapes in CAD to produce the core of your idea.
    b. Use simple materials that can be built up and taken apart quickly to replicate your drawing.
    c. Don't focus on power or transmission at this point, focus on the minimum viable product - the simplest and fastest object that "works".
        i. Team 1678 describes prototyping as part of their mechanisms and prototypes Fall Workshop: Mechanical Fabrication and Prototyping
2. ***Useful Materials***
    a. For building and structures, use materials like cardboard, wood, PVC pipe, duct tape, springs, plastics, or even old prototypes and 'broken' items from previous years.
    b. For power, you can manually rotate shafts or push/pull on sliders. Power drills are easy to attach to shafts for rotating parts. For higher fidelity prototypes, using *FIRST*® Robotics Competition motors with a battery pack (and an on-off switch or custom potentiometer!) can show how the mechanism will perform with its specification motor and/or transmission.
    c. Oftentimes, these prototypes are small, flimsy, or difficult to hold. Use clamps, vices, or weights to attach the prototype to a rigid surface, or an old rolling chassis!
        i. Weights are especially useful for determining robot performance. Team 148, Robowranglers, have a cement cinder block in their lab that they tape or tie onto bare chassis to understand how their drivetrain and chassis will operate under load, without needing to build every mechanism.
        ii. In 2018, many teams attached their intake mechanisms to old chassis, or wood planks with wheels, to see how effective they would be at collecting while in motion.
        iii. Check out part of the 2018 blog from team 3847 here: Team 3847 Blog - Wooden Chassis
        iv. Team 3847 also has a fast-prototyping concept called proto-pipe, using pvc and 3D printable joints to quickly fab and modify components at scale: GrabCAD - Spectrum Protopipe

3. ***Iterate Frequently***
    a. Your prototype should not stay the same for a long period of time. With each test run, each outcome recorded, you should change, tweak, and re-test.
    b. Have a written test plan, and for each tweak, re-run each test. Record the change, the results of the new test, and compare to previous permutations.
    c. Each iteration should comprise of one "failure" identified and attempted to improve upon. Each iteration should involve changing only one item or component at a time.
        i. For 2018, team 4911 and many others created intake prototypes, and ran a number of tests with traction wheels, then swapped for colson wheels, then used the green wheels, then tried another wheel, and recorded the efficiency of intaking game elements. The data showed the best performance, consistency, and longevity came from the green wheels.

Level 2: Improving the Concept

Once you have the basic concepts and prototype built, you can improve the process and improve the fidelity of the prototype. Higher fidelity prototypes can eventually find their way onto practice robots or competition robots and are used to continue improving the robot performance once the basic concepts have been tested.

1. ***Useful Tools***
    a. To create higher fidelity prototypes, some teams are able to turn to precision machines to quickly manufacture complex shapes. Wood/plastic are still cheaper than metal, and in most cases faster to manufacture. Teams that are able to use CNC mills and routers do so to increase the precision and tolerances of their prototypes and bring them closer to competition specification.
    b. Use old robots if you have them. Depending on the age of your team and the storage capacity of your workspace, keeping old robots around and operating can help with prototyping and testing. They already have code and power, and can be adapted to run your new prototype mechanism.
    c. During testing, camera replays, and slow-motion cameras can reveal much more fine detail about how your prototype is interacting with the game objects. Camera reviews make for great test evidence, and can show nuances when testing for repeatability.
        i. In 2017, many teams used slow motion cameras or slo-mo capture from cell phone video to view how and why the fuel game pieces were being fired from their mechanisms.
2. ***Building a Higher Fidelity Prototype***
    a. Your prototype should move from a proof of concept toward a high fidelity validation of performance. Tweaks and changes should be focused on matching production quality. First steps should be removing manual controls, replacing then with *FIRST* Robotics Competition motors, controllers, and code.

b. Once the proof of concept is complete, improving performance should be the next goal. Make the prototype operate faster and run more cycles to challenge durability.
c. Start upgrading the materials. Now is where decisions for belt, chain, polycord, etc. should be made. Wooden structures should be replaced with lighter and stronger aluminum.
d. Start adding complexity to the prototype. Some complexity that allows for rapid change of position, or part swap should be identified and added - it will save time in the long run.
    i. Specific to flywheel shooting mechanisms, teams often use slides and cams to quickly adjust gap/compression and exit angle when building prototypes.
    ii. Check out these slides describing how different teams build and improve their prototypes: Behind the Lines - Effective Prototyping Techniques

Level 3: Additional Thoughts

- Prototypes are never finished. Once they are on the competition robot, they can still be tweaked, modified and tested.
- Strategic prototyping is a thing! Use previous robots with similar game pieces (or not) to “play” the new game, try different cycles, compare cycle times and scores, test how tight certain paths or sections of the game field are.
- Many teams have documented prototypes—they have finished a lot of work for you! Elevators, four-bar-linkages, climbing/lifting mechanisms, flywheel shooters, there are existing CAD for all of the above. For certain items, skip the proof of concept, and proceed directly to a higher fidelity model.
- Converting prototypes to competition ready components - IDENTICAL is crucial. Spacing, friction, power, dimensions--these must be copied identically when producing your final version.

About The Compass Alliance

The Compass Alliance was founded by 10 teams from around the world with the mission of helping *FIRST* Robotics Competition teams sustain and grow. A growing Resource Repository, and 24/7 Call Center give anyone of any skill level the tools to learn something new or learn more from anywhere in the world. Remote teams lacking mentors can sign up for a Tag Team to be their remote guide throughout the season, and Help Hubs pinpoint where to gain access to local services other *FIRST* teams offer. Hear For You provides the resources and tools to help teams and volunteers develop mental wellness on their teams and at events. You can learn more about The Compass Alliance, find quality assistance, and get involved at www.thecompassalliance.org

About This Resource

This resource was prepared by The Compass Alliance, with the support and overview of *FIRST.* If you have questions about this resource, please contact thecompassalliance@gmail.com or firstroboticscompetition@firstinspires.org.

Revision History

Revision #	Revision Date	Revision Notes
1.0	Dec. 2018	Initial Release