Version 1.0

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Find more information about BEST online at: www.bestinc.org

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- Terry Grimley and other SA Volunteers, San Antonio BEST (Student Recruiting, Kit Descriptions and Graphics, Team Member Contract, Parent Information Sheet, Common Sense Guidelines)
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A Note from Experienced Coaches

A journey with the BEST program can be a wild river raft ride: when you reach the end you are tired but proud and you realize it's not really the end because that river keeps flowing. Mentors, teachers, and students all discover new facets of themselves as well as acquire new knowledge about the world. This manual is intended to assist and guide coaches in their journey, not serve as an absolute standard that must be strictly adhered to. Knowledge and experience from fellow travelers mix together in this manual, but every year BEST evolves into something new because not only do the uses of science and technology continually change, so do participants continually force change. One team said, “Our goal is to exceed the boundaries of what we learned the year before.”

To truly push forward the purposes of Boosting Engineering, Science and Technology, to truly push our nation forward, that is what we must strive for. So, this manual is outdated the minute you receive it, but hopefully, like maps of our early America, this one will help you start on your journey, fill the blank spaces you have not mapped, and most importantly, encourage you to “exceed your boundaries.”

Leah Martaindale Tony Cacciola Emily Boswell

Welcome Aboard

BEST Robotics has nothing to do with the actual launching of a space shuttle. Yet, over the years hundreds of high school and middle school coaches have used the BEST Robotics competition to launch students into a discovery experience that is unlike any other available to them. Skills that students learn during their participation in BEST are foundational to a lifetime of academic adventure. Teaming skills and problem-solving skills are the most obvious that students will develop. However, there are many other developments that past students have enjoyed. Don't be surprised if many of your students make (or solidify) career orientation decisions based on the insight gained through this team oriented engineering challenge. Students have made it clear to us that BEST is much more than an opportunity to have fun and build a cool robot. It is the BEST learning experience that many have ever known.

After a quick flip through the pages of this document you'll correctly deduce that it takes a lot of work to equip a team and deliver them to the "launching pad." A team that has been well prepared by their coach before the competition starts is more likely to have a successful experience. But the coach's responsibility doesn't stop when the competition begins. The role of the coach remains essential throughout the competition to exploit the educational potential of the program. A good coach is not just an interested spectator. A good coach is the team's most valuable player.

Please do NOT treat this document as instructions that should be religiously followed. Think of it only as a tool kit for you to use along your journey. Though you need to know basic information about all the tools in your kit (like where to find the tool), you do not need to be an expert user in order for a tool to bail you out of some tricky situations. Nobody is expected to retain all this information after a single reading…or several readings for that matter. It is recommended that you give the entire document a casual reading and perhaps make some lists including: "sections describing things I'll do," "sections discussing things I'll teach the team," "sections that the students can learn from by reading on their own." After a complete reading, reconsider the section "Things to Consider When Contriving a Plan." You'll then find it much easier to complete the steps in "Preparing a Team for Kickoff."

Come back to this document as your team encounters challenges throughout the season…things will make more and more sense as you go through your first season. Rookie coaches should not deceive themselves into thinking that other coaches have "figured everything out." We've already had comments from very successful coaches (with more than nine years experience) saying things like "hmm, that's an entirely different perspective. I think I'll try that this year." You'll soon learn that there is no single "right" way to facilitate a BEST team. Hopefully, the suggestions in this document will help you in implementing your own special coaching style. Know that the students will learn a great deal whether you have done everything "perfectly" or not.

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BEST Overview

Mission

BEST is a nonprofit, volunteer organization whose mission is to inspire students to pursue careers in engineering, science, and technology through participation in a sports-like, science- and engineering-based robotics competition.

Goals of the Competition

- Inspire student interest in engineering, science, and technology
- Motivate students to pursue careers in these fields
- Engage students in exciting, fun science-based activity
- Enlist business/industry to become collaborative educational partners

Attributes of the Competition

- Enhances teaching/teacher effectiveness
- Reinforces classroom learning
- Creates real-world academic challenge
- Increases students' interest in science
- Exposes students to new career opportunities
- Provides competition/fun
- Promotes school spirit and sense of "community"

Benefits to Students

- Increases understanding of technical concepts and scientific principles
- Provides real-world engineering challenge
- Encourages abstract thought, self-directed learning, and decision-making
- Promotes team building, good sportsmanship, and ethical conduct
- Produces pride in success
- Creates awareness of career possibilities

Program Specifics

- There is no entrance or participation fee for schools to compete in BEST.
- Teams of any size can enter. The school dictates student eligibility requirements. The school dictates the schedule for team meetings.
- Students have six weeks to design and build a remotely controlled robot that outperforms other robots in a head-to-head game-like competition.
- Engineers and other technical professionals from industry serve as team mentors who advise and guide students through the design and construction of their machines.
- BEST features two parallel competitions:
    - Robotics (the game itself)
    - The BEST Award is presented to the team that best embodies the concept of Boosting Engineering, Science, and Technology. This concept recognizes that inclusiveness, diversity of participation, exposure to and use of the engineering process, sportsmanship, teamwork, creativity, positive attitude and enthusiasm, and school and community involvement play significant roles in a team's competitive experience and contribute to student success in the competition beyond winning an award.
- There are three significant local events during the six-week period. Some teams will advance to regional competition.
    - **Kick Off Day (early to mid September)**
        - Game theme, game rules, and playing field are unveiled.

  - Returnables kit (r/c units, batteries, motors, etc.) distributed to teams.
  - Consumables kit (loose parts, PVC, plywood, and dot matrix printer) distributed
  - The six-week design and construction phase begins!
- **Mall Day (end of fifth week of competition)**
  - Opportunity for teams to practice driving robots on actual playing field
  - "P.R." opportunity to promote program and competition
- **BEST Hub Competition (end of sixth week of competition)**
  - BEST Award competition (optional for schools)
  - Robotics competition
  - Other awards and recognition
  - Winners advance to regional competition
- **Regional BEST Competition (mid-November)**
  - BEST Award competition (optional for schools)
  - Robotics competition
  - Other awards and recognition

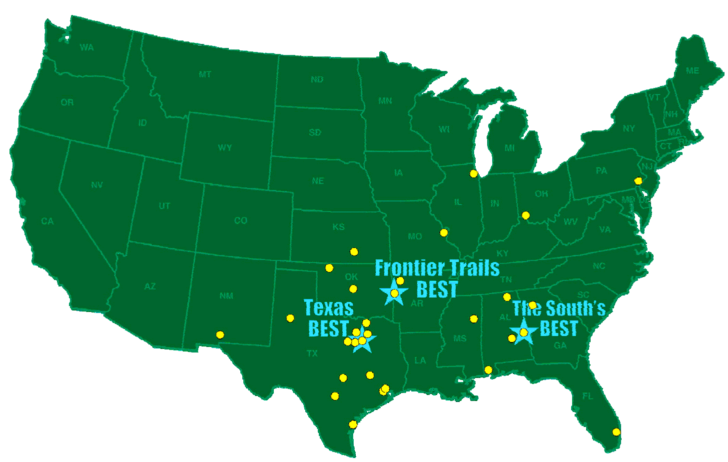
History

The idea for a BEST competition originated in 1993 when two Texas Instruments (TI) engineers, Ted Mahler and Steve Marum, were serving as guides for Engineering Day at their company site in Sherman. Together with a group of high school students, they watched a video of freshmen building a robot in Woody Flowers' class at Massachusetts Institute of Technology. The high school students were so interested that Ted and Steve said, "Why don't we do this?"

With enthusiastic approval from TI management, North Texas BEST (Boosting Engineering, Science, and Technology) was born. The first competition was held in 1993 with 14 schools and 221 students.

After learning that a San Antonio group had formed a similar program, the two groups - North Texas and San Antonio - decided to meet in 1994 for a state playoff at Howard Payne University in Brownwood, Texas. Thus, San Antonio BEST, the second BEST competition site (or "hub"), was born.

In 1995, more hubs were started as word spread: Collin County BEST (Frisco, Texas); West Texas BEST (Texas Tech University in Lubbock); and Chicago BEST. Also, that year, Texas BEST - the "state championship" - became an annual event sponsored by Texas Instruments and Texas A&M University.



BEST Hubs and Regional Competitions in the 2005 Season

Other hubs have joined in the years since and in 2003 BEST's second regional championship was born, South's BEST, at Auburn University, Alabama. In 2003, thirty-six teams from nine hubs in Alabama, Georgia, Florida, Ohio, and Illinois competed. While Texas BEST (now held at SMU in Dallas) featured 60 teams from 17 hubs in five states.

In the 2005 season the third regional championship was created, Frontier Trails BEST.

Why BEST is Essential?

- Failings of the US K-12 education system, in science and mathematics…
- Declining level of interest in such fields, especially among the "best and brightest"…
- Inadequate knowledge of science and engineering fields as careers…
- For women and minorities, a lack of role models in these fields…
- Overall, students are not as excited about these disciplines…

[Dayton Business Journal, May 2001]

Demand Exceeds Supply and that Spells Trouble[1]

> *An important aspect of U.S. efforts to maintain and improve economic competitiveness is the existence of a capable scientific and technological workforce. A January 2004 report of the National Science Foundation (NSF), Science and Engineering Indicators 2004, states that between the years 2000 and 2010, employment in science and engineering fields will increase at more than three times the rate for all other occupations. In addition, approximately 86% of the increase in science and engineering will be in computer-related positions. Simultaneous with predictions of the future scientific work force is data reporting a decline in the number of students seeking degrees in certain fields. While 33% of the undergraduate degrees awarded are in science and engineering, the portion of degrees earned in the physical sciences, mathematics, computer science, and engineering has been static or declining. Disciplines that have witnessed an increase in degrees earned have been primarily psychology and the biological sciences. There is growing concern by many in the scientific community, industry, research-driven federal agencies, and Congress about the production of the nation's science and engineering personnel.*

Never Playing the Game[2]

Robert E. Yeager identified a flaw in the way that science is often taught.

> *"We have ignored the lessons we might learn from sports. We pronounce science a fantastic game—that all should learn to play it. We spend years teaching background material, laws, rules, classification schemes, and verifications (disciplines) of the basic game. We plan activities for our students designed to develop in them specific skills that the best scientists seem to possess and use. We believe that proficiency with these skills is an important part of an education in science. It is as if we were developing conditioning exercises to train our students for the science they may actually do at a future time. Unfortunately, however, our students rarely get to play— To spend 13 years preparing for a game, but never once to play it, is too much for anyone."*

No wonder so many students lose interest and abandon the science and engineering educational pipeline…

Don't you agree that it is time to let them play?

1 CRS Report for Congress; *Science and Technology Policy: Issues for the 108th Congress, 2nd Session*; September 2004

2 U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering-A Technical Memorandum*, December 1988

Detailed descriptions of past games can be found on the www.bestinc.org website.

2004 — BEST Fever
Squeaky has the genetic disorder "BEST Fever." Your robot (Polymerizing Enzyme) is to enter his cells, denature the DNA and use the Primers to resequence his DNA.

2003 — Transfusion Confusion
Once miniaturized, your machine, and that of three other teams will work to move blood cells from various locations within a sterile field to a Cell Saver used for autologous blood transfusions.

2002 — Warp 10
It has been 10 years since BEST beginnings. Steve and Ted's peaceful afternoon is disrupted by the sudden appearance of a rotating micro-black hole. Tearing through the fabric of time, it is threatening the historic BEST game pieces. Robots have to traverse the black hole and set things straight.

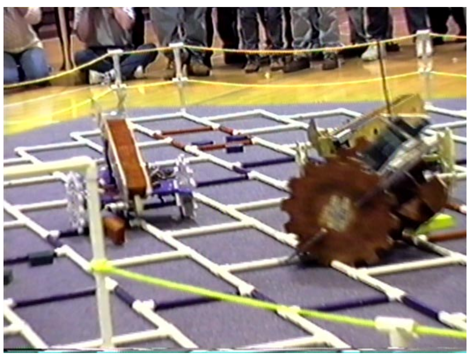
2001 — RAD to the Core
The reactor at the nuclear power plant is quickly overheating and the fuel rods must be removed. Get your **R**obot **A**ssisted **D**elivery robot to the core by crawling along the overhead beams and save the reactor.

2000 — Pandemonium in the Smithsonian
Enter the Smithsonian to retrieve technical artifacts, reset fire alarm switches, and return to a safe location. Drivers had to rely on their spotters to "see" the game floor.

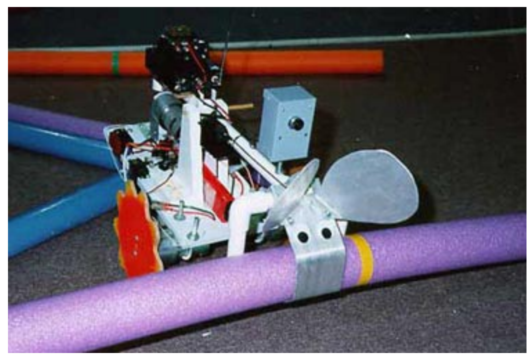
1999 — Alien Escape
Help "aliens" escape from a dying planet. Robots captured and moved "alien pods" (fuzzy balls) or multiplier game pieces onto the field "rocket" or other scoring locations on the floor.

1998 — Toxic Troubles
Pick up garbage and place it in or below a collection containment vessel. Returning the special game piece to the spotter who then placed it on the machine also scored points.

1997— Dynamite Duel
Remove sticks of "dynamite" from an abandoned mine field by placing it into an explosive-proof bucket at the top of the mine. The amount of dynamite was measured by mass and not by the number of sticks.



1996 — Block-N-Load
Score points by capturing squares on the playing field. A square was "captured" by placing game pieces in it.



1995 — TOTALly aweSUM
Gather long, tubular, foam noodles and place them in the positive area or in the opponent's negative scoring area. The team with the most positive scores was the winner.

1994 — Bumble Rumble
Gather "bumble balls" and place them into a scoring area. Each team had a high and low scoring area. The high scoring area was elevated and slanted so that if bumble balls were left unattended, they would "bumble out."

1993 — PVC Insanity
Take a short piece of PVC pipe from the edges of the playing field and place it on a goal in the center of the field. Scoring was determined by the placement of the pieces on the goal.

BEST Terminology

You're standing on the banks of an apparently raging river. Be assured that hundreds have gone before you with no more whitewater rafting experience than you have. Don't be alarmed if, after your first read through this manual, you still feel a little uncertain of how to navigate these logistical rapids. Know that though it appears to be a raging river, it is really just an amusement park ride. By design you might get a little wet, but you're likely to be wearing a grin when it is all over. Don't be surprised if you, like so many of your predecessors, discover a new favored activity to look forward to year after year. Here's a vocabulary tool belt you should strap on before boarding the ride. (Terms are listed alphabetically, not in order of significance or appearance in this manual).

BEST stands for Boosting Engineering, Science, and Technology. Remember that it is more than an acronym, it is a mission.
BEST Award – Recognition in the parallel competition, which is optional (but actually more coveted than "winning" in the robotics competition). The BEST Award competition evaluates teams in five categories, some of which are optional for hubs to include: a project summary notebook (mandatory); oral presentation (optional); table display (optional); spirit and sportsmanship (mandatory); and robot performance (mandatory).
BRI is the acronym for BEST Robotics, Inc. BRI is the national parent organization that facilitates consistency between the local BEST hubs across the country.
Coach - a term used interchangeably with "teacher," the primary adult liaison between BEST and the team. The coach is typically a schoolteacher who may or may not have technical experience.
Consumables (Kit) - the collection of raw materials provided by BEST to teams from which they must build their machine. Teams are limited to using just these items, plus a small number of defined, optional items they can add. The Consumables Kit and Returnables Kit are both distributed at Kick Off.
Driver is the member of the robotics team that operates the robot (via remote control unit) during the match.
Early Bird is an optional event held by some hubs on the third or fourth weekends of the six-week competition. It is an opportunity for teams to test drive their machines on the actual playing field. If available this event may serve as some incentive for your team to meet milestones as quickly as possible.
Game is the robotics challenge, which changes annually. Typically, the game is educational in nature; that is, teams vying for the BEST Award can research game-related topics for inclusion in their project summary notebook and other components of the BEST Award.
Hub is the local organization (i.e., steering team or committee) that hosts an annual competition. There are over 25 hubs each hosting between 12 and 30+ teams.
Interview (probably occurs at Table display) - This is a distinctly different opportunity from the Oral Presentation and generally takes place at the Table Display. This is a semi-formal interaction between the judges and the students. This interaction may occur in the Pit area.
Kick Off is held on a Saturday in September each fall. It is the event at which teams assemble to get the first look at the year's game as well as receive the game rules and kits. It marks the beginning of the six-week challenge.
Mall Day is conducted at a hub's local mall to allow teams to practice drive their machines on the actual playing field that will be used on Game Day. Typically held on the fifth weekend of the six-week competition, this event is also a great way for hubs to promote the event and for teams competing in the optional BEST Award to earn "community service points." Some hubs refer to this as "**Practice Day**" or "**Demo Day**" if it is held at an alternative location.
Mentors serve as guides or advisors that shepherd the robotics team through the technical challenges encountered during the six-weeks of machine design and construction. These adults can be engineers, technical professionals, parents, or others – no technical expertise is required, but is obviously preferred. The role of mentors is clear: advise, do not design or build.
Oral Presentation is one component of the BEST Award competition (which is optional). Teams make a 15-20 minute presentation before a panel of judges in which they provide information about their team, the engineering that was incorporated in the design and construction of the robot, and why their team's robot is the best one. Other aspects of the team's progress can be included. The presentations are optional at the hub level, but mandatory at regional competition.

Playing Field (sometimes called the game floor) is the field on which the robots play the game. It is typically made of plywood, PVC, and lumber and is set up on regular indoor carpet. Although the game changes annually, the playing field tends to be 24 feet square.

Project Summary Notebook must be provided by every team and is evaluated by technical professionals or engineers. The notebook documents the process the team used to design, build, and test their robot. The notebook is not only a part of the BEST Award, but is required of every team.

Returnables (Kit) is often referred to simply as "Returnables." This set of equipment is provided (i.e., loaned) to each team at Kick Off and includes such items as large and small motors, r/c units, speed controllers (or DSP cards, as the case may be), batteries, battery charger, and other items. The equipment is purchased by the hub and is returned to the hub after Game Day.

Spotter – this team member assists the driver during the match. The spotter is usually positioned away from the driver to provide a strategically different perspective of the playing field.

Table Display (with or without interview) - an optional category within the BEST Award, the name itself is actually a misnomer. In actuality, each team competing in this category is given an assigned space – it can be an actual tabletop (six- or eight-feet in length) or it can be an area. The displays are judged on the local promotion of BEST, use of technology, creativity, and publicity activities within the community.

What to Generally Expect

By design, the program has been restricted to a six-week period to facilitate high intensity while mimicking time constraints that real-world engineers routinely experience. Though the "competition" only lasts six weeks, many schools have found success by integrating it with various semester-long classroom activities or an after-school club that meets year round. The next section will discuss some of the implementation plans that we've seen. Regardless of the implementation plan, you can expect the following during the actual six-week competition.

Time Required

An experienced adult can build a prototype-robot from scratch in 40-60 man-hours working alone. It will take longer for students and much longer if they do not have experience with tools. However, there should be many more students to share the load. So, expect to schedule about 40-60 hours of extended team meetings during the six-week period and 1-2 weeks prior to kickoff. A disciplined team could probably build a minimum performance robot in as few as 20 hours.

Teacher Participation: Because teachers need to attend every meeting, you should have at least one part-time assistant coach. It would be a good idea to have one head coach and a second coach to direct the BEST Award activities. Then have additional teachers volunteer to monitor single evening sessions.

Week	Primary Objectives	Sample Meeting Time*
Weeks Before Kickoff	Develop team organization, practice drawing/tool safety, review past robots, orientation to the engineering process, and strategize for BEST Award.	2 hour sessions 1-3 evenings each week. Beginning the first week of school is not too early.
Week 1 (following kickoff)	Study the problem, brainstorm conceptual solutions, prototype using cardboard, get electronics working (on tabletop but not on robot). Get long lead-time marketing efforts going.	2 hour sessions on 1-2 evenings. 2-4 hour Saturday session for sketching and rudimentary prototyping.
Week 2	Choose embodiment designs for base, arm, and gripper. Create detailed *sketches* of individual parts. Construct common robot parts (motor mount, shaft couplers, and pulleys).	2 hour sessions on 2 evenings. 2-4 hour Saturday session for basic prototyping.
Week 3	Produce formal drawings for common robot parts. Produce other parts from refined sketches. Assemble working robot "base" with basic working arm…begin driving. Detail planning of marketing booth. Outline marketing presentation.	2 hour sessions on 2-3 evenings. 4 hour Saturday construction and testing.
Week 4	Construct final gripper and begin formal drawings of all tested parts. Build basic marketing booth with placeholders. Compile information into presentation.	2 hour sessions on 2-3 evenings. 4+ hour Saturday session to finish construction of all major parts.
Week 5	Practice driving to identify problems. Refine design of individual parts and document changes. Compile design notebook. Practice presentation.	2 hour sessions on 3 evenings to refine parts. Long Saturday session for marketing team to finish major construction.
Week 6	Practice driving, polish driving strategy, polish gripper, polish marketing efforts.	2 hour sessions on 4 evenings (in each meeting alternate driver practice and parts refinement).

* Minimums are suggestions for teams that want a performing robot within a low stress environment. Robots can be built with less time, but it is unlikely that the students will gain any insight into a formal engineering process. Required meeting length and frequency will vary based on the number of conflicting extracurricular activities, school policy, amount of team discipline, and how high the team sets its sights. No amount of time can guarantee a win for either the robot or the BEST Award.

General Responsibilities of the Head Coach

- Facilitate team meetings each week (evenings and weekends) until competition day.
- Facilitate student permission slips and supervise any student transportation.
- Facilitate introductions between students and volunteers. Monitor interactions.
- Determine student eligibility, ensure student involvement meets school criteria, and secure parental consent to participate.
- Arrange for a design and fabrication facility (e.g., school's shop classroom).
- Provide team guidance in areas such as recording team events, promoting the competition within the school, cheering section, tee-shirts and caps, taking photos, etc.
- Help maintain student participation, motivation, and discipline.
- Help identify and develop team leaders.
- Facilitate coordination with other student groups (shop class, programming classes, cheerleaders, etc.).
- Help celebrate achievements of the team.
- Encourage sponsor appreciation through student letters and phone calls.
- Encourage mentor involvement.
- Monitor all fundraising and advertising activities the team may engage.
- Ensure that deliverables are returned to BEST according to schedule.
- Ensure team conformance to school policies.
- Ensure team compliance to BEST rules and deadlines.

You can use the following calendars to lay out the first draft of your team's meeting schedule.

September:

Mon	Tues	Wed	Thurs	Fri	Sat

NOTES: Kickoff is on one of the first three Saturdays of September. Check with your local hub.

October:

Mon	Tues	Wed	Thurs	Fri	Sat

Practice day is five weeks after kickoff and game-day is at the end of week six.

BEST Scenarios We've Seen in the Past

It seems that every school has their own unique implementation. Some completely integrate the robotics program into their curriculum and others participate solely as an after-school club. The following hypothetical schools might help you imagine the breadth of possibilities while also hinting at characteristics shared by many of the successful teams.

School A:

A school in a very small farming community has 300 students in grades K-12. A physics/science teacher (for several grades) starts an after-school club and invites students in all grades to participate. She rearranges some classroom topics to coincide with BEST so that the robot serves as a good hands-on example. (Note most of the physics concepts are covered in the spring, but she will have the robot there as a reminder of what the students did in the fall.) Only about eight students are active in the club the first year. The students manage to build a good robot, but they mostly miss the connection to "real" engineering. In the second season, the drama/English teacher gets wind of the BEST Award competition and really goes to town. The club triples in size as 16 new students come aboard and focus strictly on the BEST Award. The team manages to get most of the student body involved in one way or another. The team visits elementary schools, is given some time at the high school pep rallies, has robot demonstrations at lunch, recruits local businesses to provide some meals at long team meetings, organizes an "all community day" at the local park with lots of general family activities, and even has the first graders writing poems about robots. The new emphasis on the BEST Award attracts additional technical mentors to the program and they teach all the team members to really consider the design process as a formal approach to general problem solving. In a couple of years, elementary students have heard so much about BEST that they are looking forward to being "old enough" to be on the official team.

School B:

Private schools are just as effective at BEST as any other school. The technology teacher at this one has a lot of freedom and chooses to fully integrate "building a robot" into his classroom. He doesn't plan to focus very much on the BEST Award, but does impose a very disciplined and formal approach to problem solving. Students are allowed to choose from CAD projects, computer animation projects, or computer analysis/presentation projects for their semester projects. In the process he doesn't realize how well his team is doing at achieving the goals of the BEST award. Their team places third in the BEST Award just by focusing on good design (and not really engaging any marketing). His original plan was to do everything during class time. After the second week of competition, the team realizes that there will have to be some outside of class activity. The students decide to meet at a mentor's garage each Saturday to build from the CAD drawings that have been produced in class. Because they have not been meeting after school, they are behind the progress of other teams. They don't have a fully working robot at Mall day, but because they have a thoroughly thought out design and well-detailed drawings they are able to quickly proceed through the construction. The principle excuses the students from class for a single day and they are able to complete the construction just in time. Unfortunately, they did not have much time to practice driving the robot. A few driving mistakes kept them out of the final four.

School C:

There are a lot of competing activities here at this 5A school and it is hard to get the attention of the general student body. A zealous teacher started this school's team and established an after-school club several years ago. The club maintains over 40 active members (meeting Tuesday and Thursday nights and long building sessions on Saturdays). The founding teacher was eventually assigned conflicting duties and had to hand off to another teacher. The new teacher really doesn't have to do much because the team has a culture of experienced students mentoring the freshman/sophomore students. The pipeline is kept full because the BEST students are active in recruiting at the local middle schools where they mentor the middle school robot teams as much as possible each season.

School D:

Local home-school students wanted to participate but due to liability reasons, no other teams could invite them in. A dozen such students got together and formed a team. They all agreed that absolutely NO work would be done on BEST until all their other schoolwork was done. They have weekly meetings with the entire team...but subteams meet more often in order to finish their assigned tasks. They use whatever tools they can find in their collective garages. There are absolutely NO school resources available. So, they have to be creative in recruiting support from local businesses including mentor support from local engineering firms. Consequently, they develop a very successful marketing program. They routinely place in the top three in both the robot competition and the BEST Award competition.

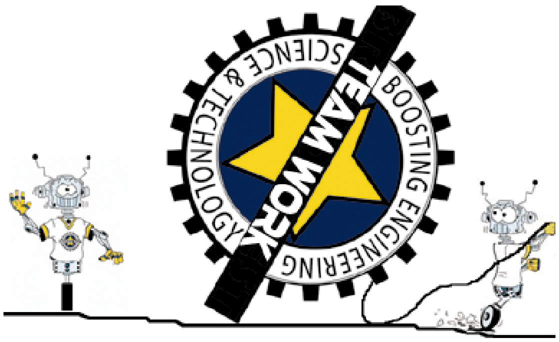
School E:

This is the first year to have an official "robotics" class at this school. The administration loves the BEST concept but is not personally familiar with the intensity required for young students to actually build a robot. The new coach has the students practice communication skills and drawing skills for the first couple of weeks of the semester. He wisely separates the students into subteams each with a different function roughly coinciding to groups that might be seen in a large engineering project. The students learn the engineering process quickly and some become effective draftsmen. Hence, the coach expects this season will be a cakewalk. After kickoff, the coach is quickly made aware that though these young students have a lot of creative ideas, very little actual building can be accomplished in a 45 minute session. He learns that one adult is required for every subteam in order to keep the students productive. Luckily, parents begin attending class and keep the subgroups on task. He puts together some special after-school building sessions, but it's hard to find technical mentors at such short notice. With two anxious Saturday building sessions, the team pulls together a robot...but not a very good one. The core building group spends long evenings in the last week of the competition in order to debug the robot. They have learned their lesson. Next year, the class will be scheduled for the last period of the day and any interested students will be allowed to stay after class for "robot club" (which is open to the general student body). Class topics will directly relate to the competition. Instead of cramming the last three weeks with rushed activity, they will schedule 5 hours of meetings outside of class beginning two weeks before kickoff. This will ensure that the students have time to digest new information and hone their skills. The challenge will be working out transportation for these younger students who stay after class.

School F:

This final example is another large school with older students. They have a committed technology class and an experienced technical coach who knows where the typical challenges come from in designing a machine. Hence, this coach can prevent the team from going too far down "blind alleys." This makes the team more efficient. Over time the information has been very well integrated into the semester long class. Because this class is restricted to junior and senior students, the team tends to have better building skills than typical BEST teams. This is a double-edged sword. They can quickly prototype ideas. However, their increased confidence makes them somewhat lackadaisical and they don't schedule many after-school meetings. The result is they always have a working robot on competition day, but it is not always a good performer. They do not have a BEST club like some schools. Without the established "mentoring culture" of a BEST club, they find it difficult to mobilize the very large student body. Though they actively participate in the BEST Award competition, without a club these students have to start at ground zero each year.

Things to Consider When Contriving A Plan



By the end of the season some new coaches will simply be looking for a place to hide. If you haven't thought things through, the momentum of the team's enthusiasm can be overwhelming. If you want to be more like the robot on the left...than the robot on the right, then you'll need to do some planning.

With the information you now have, try to visualize what your team meetings will look like through the course of the six-week competition. Imagine you are an observer and simply take note of the things you expect to see. Also, try to imagine what you want your team to reflect on as you look back on the season. The following questions might help you.

How high of a goal am I willing to facilitate?

- Am I willing to commit to whatever it takes to "win" or do I want to commit a specific number of hours each week?
- There are two competitive branches (robot competition and BEST Award competition). Am I going to emphasize one over the other?
- Do I want to focus on learning the underlying principles or just get through to a final product? i.e., anyone can build a robot, but can you help your team learn the skills that will benefit them for life (formal problem solving, good teaming, how this stuff relates to careers in engineering, science, and technology).

Will BEST be integrated into the curriculum or strictly as a "club"?

- Curriculum integration can be effective before, during, or after the six-week competition.
- Candidate classes include Physics, Science, Math, Problem Solving, Public Speaking, Computer, and Technology.
- Do I want to investigate the DSP (digital signal processor) possibilities and the Infinity Project[3]? Some hubs are allowing teams to put these on-board computers (DSPs) on their robots that provide very good tie-ins to computer programming.
- Do I expect my students to be able to stay on task and actually produce things from raw material during a regular class?
- Are my students old enough (independent enough) to regularly attend club meetings?
- Are my students too busy for an after-school club? Is Saturday an option? How many Saturdays can I, or assistant coaches, commit to?
- What creative combination of in-class activity and outside-class club meetings can I think of?

How much of the required "adult" participation will come from me and how much from parents, mentors, and other coaches?

- How does my peer group typically respond to such programs?
- What level of parent involvement is available?
- How heavily will I have to rely on a technical mentor? (Do I need mentors at every meeting or just once a week?)

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[3] You can read more about the Infinity Project curriculum online at http://www.infinity-project.org.

Elements of a Good Plan

When you are ready to work out the details of your implementation plan, consider the following elements: (space has been provided below each item for you to record your ideas)

- Number of hours to be committed in each week of the six-week schedule (and in preparation weeks)

- Meeting logistics like how participants get to/from meetings, will meetings cross meal times

- How much adult support will I need at each meeting? (Younger students actually using tools will need no less than 1 adult for 3-4 students. Younger students working on non-robot related activities need less monitoring, but will still need some constant adult presence to keep them on task.)

- Who do I know that has experience with electronics, woodworking or metalworking, construction, and drafting?

- What steps (and by what date) will I recruit students, parents, assistant coaches?

- What eligibility requirements will I impose for team membership?

- What will be my first draft budget (table display materials, other BEST Award materials, team t-shirts, snacks/meals, tools, prototyping, and other class supplies)? It is NOT necessary to spend any money to be successful in all parts of the program, think small but be realistic $100-$500.

- How much of the budget will come from the school and how much will my BEST Award team need to solicit from the community? (Teams can borrow tools, use scrap cardboard and materials for prototyping, get local businesses to supply snacks/materials.)

- How will safe tool use be trained and monitored?

- What will I expect each student to learn? (Will I hold them accountable for learning it?)

- What resources will the school provide?

Recruiting and Informing a Team

Recruiting Staff Support

There are many coaches who sponsor teams with little support from other teachers or school administrators. Experience shows that this is NOT the preferred approach because, at the very least, a school representative needs to be present at every meeting. If the coach is flying solo, then the hours can add up quickly. Further, though the students will benefit from simply participating, their experience can be significantly enriched if their coach has the time and resources to "formalize" some of the things they are learning. A proactive coach (a trained educator) will want to ensure that the students translate their newly acquired "project specific" skills into general life skills. The only way a coach is going to have such time available is if he/she is sharing the workload with other teachers. Yes, the technical mentors are able to provide the technical information during any given meeting. Yet, it cannot be assumed that the mentors are skilled teachers. When recruiting staff support it is best to have diversity if possible (i.e., a coaching team consisting of specialists in English, Physics, and Shop would be better than a team of three shop teachers).

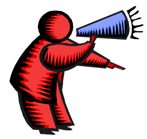
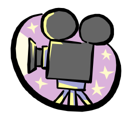
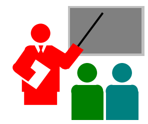
Things Your School Administrators and Peers Need to Know

The school administrators may not have time for all the details. To support your request for support, you might want to present them with the following information:

- Mission and Program Specifics described earlier.
- BEST is unlike many extracurricular activities in that the skills learned are required by just about every person in society. These include teaming and problem solving.
- Well-implemented BEST programs change student lives…not just their grades. Countless participants have changed their career intentions based on their experience in BEST.
- Your implementation plan and project meeting hours outside of normal school hours. If you can get another school representative to "baby sit" during some of these hours, that will free you up to work on enriching the experience.
- Emphasize the fact that a typical BEST coach will invest as much as a football coach does while the season is on.
- Quotes from the section "Why BEST is Essential."

Recruiting Students[4]

One of the unique aspects of the BEST competition is that it can involve many parts of the student body in the preparation for competition day…it's not just limited to those students who design, build, and operate your robot.

Students are probably best at recruiting other students, but you'll need to get a core group together first. Don't take the easy road and just invite the students who "have always been into this kind of stuff." Remember that we want to open doors of opportunities, even if the students have partly closed their minds to technical ideas. So, focus on diversity from the very beginning. You can find a recruiting flyer example in the Example Documents section of this manual. There you will also find a short video that can be played over the intra-school video system during announcements or on computer displays during lunch. Once you have an excited core, then turn them loose and grow the team as much as possible. Get the following groups and school organizations involved:

- Your school Journalism Department
  - Year Book coverage
  - School newspaper articles
  - Still and video photographer coverage
- Pep Squad members to cheer at the competition
- Band members to play at the competition
- Art students
  - Prepare banners for competition day
  - Help design the look and style of your robot
  - Design the team's logo and tee-shirts
- Fund Raising - "Non-Tech-ies" can help your team raise money in the event you advance to regional competition, want to buy tee-shirts, build a practice field, etc.
- Technology Department
- Computer simulations of robot strategies
- Video productions for marketing

Very successful schools are able to create enduring robot clubs. Team camaraderie is built year round and older students can mentor younger students as they anticipate the upcoming season each year. The more self-pride that is built into the team, the better the competition experience is likely to be. You can find an example club-charter in the Example Documents section.

Things Prospective Students Need to Know

Students need to make an informed commitment to the team. As with any team experience it is good to spend some time covering the scope of the competition and what is expected of each student. Having each student sign a team contract may help circumvent problems down the road. Look for an example in the Example Documents section.

[4] Used with Permission, "How to Get your School Involved," Terry Grimley, San Antonio BEST.

Recruiting Mentors (print this section for your mentors)

The adults who are working with a team are classified into two categories: coaches and mentors. The roles performed by these two groups can overlap quite a bit depending on the skills of the various individuals. In short, the coach is the team facilitator with a vocational connection to the school sponsoring the team. The mentor is an adult with some technical, engineering, manufacturing, or problem solving experience that can help the team overcome practical challenges. Additionally, both the coaches and the mentors should provide some insight into the role that engineers, scientists, and technologists play in society. Prospective mentors should be informed ahead of time that the school may conduct a personal background check before they are allowed to work with any students. Finally, it is the teacher's responsibility to teach the mentors how to interact with the students (including all the information in this section). Teachers should make it clear that the mentors have been invited to participate, but that invitation can be retracted if they do not conform to team, school, and BEST policies.

Things Prospective Mentors Need to Know

A mentor will only fully understand what it means to be a BEST mentor after working closely with a team throughout a season. However, you can give them a head start with the information in this section. Above all you can assure them that mentoring is a LOT of fun…when done correctly.

BEST is…

- a simulation of real world business and engineering environment.
- an opportunity for students to learn Engineering, Science, Technology, and Team concepts.
- a fun and exciting competition to intrigue students into Engineering, Science, and Technology pursuits.
- an opportunity for adults to share enthusiasm and knowledge of their chosen career.

BEST is not…

- a pursuit of scholarship funds.
- just another extracurricular distraction.
- a competition for coaches and mentors.
- a "win at all costs" program.
- focused on fundraising.

The team goals are…

- to construct a robust machine that is simple, reliable, flexible, and strategic.
- design and implement an effective marketing plan.
- learn from the six-week development process…not just compete on game-day.
- exercise good sportsmanship.

Useful Mentor Skills include:

Science	Web authoring
Mathematics	Technical and creative writing
Engineering (any discipline)	Organizational and publicity skills
Practical mechanical / electrical skills	Artistic / graphic arts
RC hobby and "techie" skills	Public speaking
Tool safety (woodworking, some metal)	Spirit leading

A good mentor will…	**A good mentor will not…**
• ensure that the student teams approach the design and construction in an orderly and methodical manner. • explain the importance of schedules and budgets. • ensure that students consider all phases of the contest. • explain brainstorming techniques. • discuss methods for evaluating design concepts. • describe prototyping and testing methods. • ensure all rules are followed. • assess skill levels of students and utilize accordingly. • set an example (be on-time, ready to work, know when to play and when to work). • **resist temptation to improve students' designs and executions.**	• take over. • force your own ideas on the team. • design or build the machine yourself! • design or implement a marketing plan. • make decisions for the team. • put down ANY student or the team. • become uninterested or too busy. • violate any rules/requirements.

Things that are reserved for the students to do:

- Review the rules and question all loopholes.
- Design and construct the machine with adult supervision and guidance.
- Document all design, manufacturing, and testing.
- Perform and document any associated research tasks.
- Lead any media and community relations activities.
- Conduct industrial espionage.
- Demonstrate sponsor appreciation.

Advice from your predecessors…

- The students will get the most from the process if they do the work.
- Pose questions to make the team think through ideas completely.
- Students don't naturally know any formal problem solving process. Someone will have to formally present one to the team. It won't hurt to post it on the wall.
- Students working without adult presence make few quality decisions.
- Very limited progress can be made on the robot without mentors present.
- Become familiar with the KIT parts (both the returnable kit parts and the consumable kit parts); see Kit Introduction.
- K.I.S.S. (Keep It Simple, Silly) and don't forget maintainability.
- Set a hard-and-fast timeline for subsystem unit completion. Schedule, Schedule, Schedule!! Plan to FINISH by Mall Day… this includes preliminary testing. Do not accept any excuses for not meeting deadlines. This is the biggest challenge for Coaches/Mentors!!!
- Construct a portion of the field for testing.
- Build the base ASAP so team can be driving and practicing maneuvering.
- Concentrate on driving as much as design - half of a team's success is great driving skills.
- Trim waste and excess but only after testing the assembled system…it's easier to drill another pivot pin hole than it is to recut an entire arm linkage.
- Be realistic. Don't let your team get distracted by pursuing too much…face it, your robot can't fly!!! Get the basics done before trying anything elaborate. Most teams need the whole six-weeks just to have a robot that works.
- Don't allow your wheels to fall off!!! All designs need a good way of attaching "wheels" to the motors. You should be testing your drive system before week three. Make it easily adaptable to multiple "wheel" alternatives. Don't accept a design that requires constant maintenance.
- Even a weak robot can outperform others if driven well. So, make time for your drivers to practice.
- Build spare parts (for critical systems) and bring them to game day.
- The team will adopt the spirit and sportsmanship of actively involved mentors.

Engineering Process Quick Reference

The information that follows does not replace the extensive discussion that can be found in the *Design Process* section. This summary simply highlights specific cautions that the mentor should keep in mind at each step in the design process.

1. Carefully define the different tasks that must be performed to accomplish your goals:
   - You probably need something to make your robot mobile.
   - You probably need to pick up and place scoring objects.
   - You may need to move other objects around.
   - Encourage thought about both offensive and defensive strategies.
   - Do NOT encourage/allow destructive strategies.
   - Understand the capabilities of the components (motors, servos, etc.).
   - You might use preliminary brainstorming sessions to narrow the problem statement.
2. Brainstorm conceptual solutions to each of the subfunctions that make up the problem.
   - Generate as many different ideas as possible.
   - Don't discount any idea, keep a verbal description of every idea.
3. Use a decision matrix to choose a conceptual direction.
4. Brainstorm embodiment solutions for each subfunction in your chosen conceptual direction.
5. After the brainstorming session, draw sketches of each of the solutions.
   - Your sketches should have enough detail to convey the idea to a nonteam.
6. Narrow down the ideas, then use a decision matrix to make a final choice.
   - Simple construction is preferred.
   - Flexibility to accommodate different strategies is preferred.
   - Modular components are preferred (in case the design changes direction).
   - Reliability in an aggressive competition environment is required.
   - Minimized dependence on driver skill and forgiving of driver error is preferred.
7. Choose the best idea and then start making detailed drawings or prototyping the idea.
   - Design before building.
   - The drawing should have enough detail so that you know exactly what parts of the kit you will use. Most ideas seem reasonable until you get to the details.
   - Cardboard layers can be glued together to build rigid mockups.
8. Make sure you finish building in time to do a LOT of testing.
   - Test subassemblies.
   - Practice driving the machine.
   - Practice driving some more!
   - The best teacher is our own mistakes…but it feels much better if those mistakes aren't revealed on game day!
   - Redesign as necessary but do not disassemble a working machine for long periods of time. That time should be used for driving.
9. Document everything.

Getting Parents Involved

Parent support is not required, but it will greatly reduce the coach's workload! At the very least each parent must be very informed and supportive of the time commitment that is required of his or her student. You can find an example take-home informational flyer in the Example Documents section. In addition to sending the information home with the student, you should have a parent group meeting. This meeting is especially important for younger students. At this meeting you can pass around signup sheets for attending team meetings, supplying snacks for team meetings, and perhaps donating prototyping materials. You may even identify potential technical mentors or ways to get their companies involved.

Tips:

- Require parent permission forms of all team members. Don't forget a photo-release form if your team will be posting names or images anywhere.
- Hold a parent information meeting before kickoff to inform and recruit volunteers. Show one of the BEST informational videos to get their attention.
- Get parents involved in constructing the practice game floor.
- Email weekly updates on the team progress and plans. Students can upload status information and team pictures to the team website. A meeting schedule e-mailed each week to the parents will help the students make it to the meetings on time.
- Don't be afraid to ask parents for support. If parents are directly asked, they generally help.
- Guidelines for parent participation are generally the same as those for mentors.

Things Parents Need to Know

- BEST is unlike many extracurricular activities in that the skills learned are required by just about every person in society. These include teaming and problem solving.
- Well-implemented BEST programs change student lives…not just their grades. Countless participants have changed their career intentions based on their experience in BEST.
- The cost for these benefits is an extensive outside of class commitment including three Hub events (typically held on Saturday).
- Parents do not have to be "engineers" in order to be mentors. Refer to the prospective skill list in the mentor recruiting section.
- In addition to mentors, the subteams will need simple adult supervision to stay on track.
- Nonschool employees will be actively involved with their student. All adults should have background checks before interacting with the students.
- There are inherent dangers working with and around tools.
- Finally, encourage them to attend and cheer on competition day! Their teen will appreciate their presence and they'll have fun cheering. They can help celebrate your team's accomplishment on competition day.

Preparing a Team for Kickoff[5]

Congratulations! You've decided to go the extra distance to provide your students an educational experience that they will value for years to come. Now, you need to get all your ducks in a row. This section will help you get things started. Just imagine a mission control countdown, proceed step by step, and get ready to launch your team into a successful robotic experience.

Countdown...

10. First, you need to make sure you understand the big picture and basic facts when it comes to BEST as described in previous sections of this manual. Open the lines of communication with your local hub to let them know you are interested. A complete list of hubs can be found at www.bestinc.org. Monitor the local hub website (and other hub websites) for information/ideas that might be helpful to you. Make sure you know the registration requirements and deadlines for your hub.

9. A myriad of implementation options exist (see BEST Scenarios We've Seen in the Past). Each school seems to have its own unique way. Consider various implementation options and make a general plan for your team.

8. Armed with a plan and the background information about the program, you can do some preliminary student recruiting and assistant coach recruiting. If it is typically difficult to sell your peers on new ideas, then you might want to find the students first, then use their influence to help recruit assistant coaches. (Use the Recruiting and Informing a Team section of this manual.)

7. Think through the plan and make a list of resources that you will need to implement the plan. Work with administration to determine how much support you can expect from the school and how much you'll be asking from the community. You should be willing to modify your plan in order to maximize peer support and student participation. Such flexibility will reward you later when there are others to share the load.

6. Start gathering interested students. It is never too early to start having team meetings. Truly successful teams form a "club" that meets year round. The administration, other teachers, and other students will be easier to recruit if you have a core of excited students already in place year after year.

5. Prepare paperwork that will be used by your team (permission form to participate, safety contract, safety test, "club" participation contract, etc.). See Example Documents.

4. You've already established informal communication with the local hub. Make sure you follow the formal registration requirements and submit the team registration forms according to their guidelines. Team signup is generally in the spring. Hubs may or may not allow late registration in August and September.

3. In August, exercise a student recruiting campaign and begin regular club meetings. Club meetings will build camaraderie while providing an opportunity to teach members some basic technical skills (teaming exercises, the design process, drafting skills, tool/safety training). The team organizational chart should be finalized here.

2. Have a parent informational meeting to convey the difference between BEST participation and the typical school program...and the importance of parental involvement. Convey the discrete time frame involved and recruit regular participation for the duration of the program (six-week competition plus one-two preparation weeks).

1. Take your prepared team to the local hub kickoff meeting...and Blast off!

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[5] Reprinted with permission; "Brazos BEST Coach Informational CD"; Dr. Michael Wienen; Brazos BEST

Weekly Tips[6]

Week 0 (Before Kickoff Event)

Overall Team Objective:

Get Things Rolling Early

All team members need to know what is expected of them, the basic team organization, their role on the team (design, production, marketing, etc.), protocol for team interactions, and the steps in the design process. Of course, the team must also create a meeting schedule and plan significant milestones in the design process. This all needs to be done before kickoff, which is generally very early in the semester. So, your team should begin meeting as soon as possible. Several weeks before kickoff would not be too early. Very successful clubs eventually meet year round and continually work on their relationships and teaming skills. Don't forget that teams of any size and in any environment have to go through an introductory phase…sometimes called the "forming" and "norming" stages[7]. These pre-kickoff meetings provide an opportunity for the members to get to know each other. But more importantly, they are an opportunity for students to learn how to work with one another and practice their assigned team roles. A team that operates fluently will be less dependent on the coach when making day to day decisions. All teams should aim to experience the forming and norming team stages before kickoff. Established club teams that meet year round can gain the advantage of having gone through the other stages of teaming as well. During this time, the team can access the school's photo record of past competitions and local/national competition webpages for both technical ideas and marketing ideas.

Technical Team Objective:

It is impossible for the teams to seriously engage the design process before they know what this year's challenge is. However there are some productive activities that can be done even before the kickoff meeting. Team members can learn and practice tool safety, steps in the design process, technical drawing, technical documentation, and use of official design decision matrices. The team can also review past challenges to generally understand the scope of what to expect. Further, they can analyze technical designs that they have seen other teams implement in the past to understand how to achieve various motions and force transfers. There are some basic elements that are common to all robot designs (e.g., motor mounts). The team could get warmed up by going through the design steps for these parts.

Marketing Team Objective:

The marketing team efforts will not be limited by the technical requirements of the competition challenge. Therefore, the bulk of their planning can be accomplished before the kickoff event. In many cases even the theme can be chosen and developed if the theme of the competition has already been published. The team will need to create a budget so they know their fundraising needs to accomplish their plan and how much of their plan can be accomplished with various in-kind gifts. Remember that the objective is to Boost Engineering, Science, and Technology. Review what others have done in the past then try to expand the boundaries.

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[6] Images in this section based on logo and character designed by Chris Hunter, Brazos BEST. Used with permission.
[7] Jack Orsburne and Linda Moran (1990) describe the stages of a team as Forming, Norming, Storming, Performing and Adjourning.

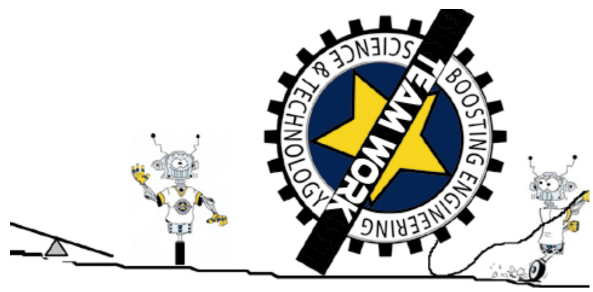
Week 1 & 2 (Following Kickoff Event)

Technical Team Objective:

This first week may be the most important week of the competition. **It is paramount that the coach remains vigilant and keeps the team from rushing through the important first steps in the design process.** You cannot create a robot in this first week, but your team can certainly make decisions that prevent a robot from ever materializing. The first priority is to create a problem statement and function structure. Then the team will progress through the conceptual design phase and the embodiment design phase, respectively. In both phases, make sure to document all ideas that are generated and use a decision matrix to make your team decisions. It is important not to engage prototyping too early in the process. Prototyping will slow the idea generation process and tend to impose unnecessary constraints on the imagination. When ideas stop flowing and a decision matrix is employed to choose the better ideas, then prototype the chosen embodiments out of expendable material (cardboard).

Creativity will be almost explosive in the first week following kickoff. The coach should work hard to make sure the team documents all ideas…even the less desirable ideas. It is common place for a rejected idea to be reconsidered later when the design changes direction, or when new information is learned, or as a supplement to the chosen designs. **The tendency to quickly choose an idea and immediately begin building should be fought at all cost.** The odds of choosing the best idea based solely on popular vote in the first meeting are extremely small (probably zero). To maximize the chance of developing a good design and to fully appreciate the engineering process, the team must take the time to document all their ideas and their decision-making process. This is an important step in the creative process that will likely lead to more ideas and unexpected combinations of existing ideas.

Left alone, these meetings will tend towards chaos as every designer chooses their own favorite idea and refuses to consider the merits of other ideas. It is the coach's role to keep the meetings productive and help the team move forward instead of in circles. It is often beneficial to revisit past decisions, but it takes disciplined maturity to recognize when such reconsideration becomes counterproductive.



The first meeting after kickoff (which can be on the same day as kickoff) must be a "problem identification" meeting…**not** a brainstorming session. Everyone must be thoroughly familiar with the problem, constraints, and available resources before trying to share their ideas on how to solve the perceived problem. Solving the wrong problem is among the worst things a design team can do. After a thorough discussion of the rules and available resources, the team should create a formal problem statement.

Only after the general problem identification worksheet is completed can a disciplined brainstorming session be conducted. For experienced designers, a brainstorming session at this point would be premature. However, novice designers will need this abbreviated brainstorming to reach the next step in the design process, which is to define a function structure. We'll use the results of this initial brainstorming not to identify the eventual solution, but to simply identify the subfunctions of the design (but don't tell the team this). The following are the recommended steps in week one and week two:

1. Individually read the rules and list of available parts.
2. Have a thorough group discussion of the rules.
3. Create a draft problem identification worksheet (including generic problem statement, constraints, and resources). This problem identification worksheet will be redone soon.
4. Subdivide the team into groups of 4-6 students and conduct formal brainstorming session (make sure to follow the brainstorming session rules including document every single idea).

5. As a team, compile the ideas on the blackboard, grouping them under generic solution category descriptions as the team identifies the categories. (e.g., given a challenge to collect and sort balls from the field, the solution categories might include: controlled gripper for many items simultaneously, controlled gripper for single item at a time, cast a "net," continuously-operating item collector, and focus on defense).
6. List the advantages and disadvantages of each solution category (not the specific solutions themselves). Most characteristics will vary on a continuous scale (for example, "requires driver skill," "handles a diverse array of tasks," "slow point accumulation," and "results are random or uncontrollable.") Such scales can be qualitatively broken into high, medium, low values.
7. Use a decision matrix to choose the preferred solution category (see the detailed discussion on How to Create a Decision Matrix).
8. Use the chosen solution category to recreate the problem statement. This time the wording **should be** biased to the solution category but still **not** biased to any specific concepts within the category.
9. The students should now be able to define the subfunctions of the problem. For example, if the design challenge is to score various balls in various scoring containers, then the subfunctions might include collect the balls, carry the balls, deposit the balls, and block the opponent. Note that by separating the various functions (collect, carry, and deposit), we have opened up the solution options beyond a simple arm to reach out and manipulate the scoring items. Now, we can consider solutions where the three functions are conducted by completely independent systems. Not only will this increase the number of possible solutions, it allows for a natural division of a large design team into subteams, each assigned a specific function.

[Three subfunctions are present in any design, the electronic control system, motor mounts, and shaft couplers. These three systems can be designed independently from the rest of the robot. It is recommended that two students be assigned to each of these subfunctions and removed from the other student efforts. If these subteams work in parallel to the rest of the group, then these common parts will be waiting for the rest of the robot instead of holding up the final assembly. One requirement must be imposed on these sub-systems. They must be generic and adjustable so they can accommodate all possible robot configurations. They should be developed using the same design process as the rest of the robot systems (problem identification, search for solutions, analysis, decision, documentation, and production) but, because of their simplicity, the process should take less time.]

10. Brainstorm conceptual solutions for each subfunction, either as a team or as subteams. The ideas should be thoroughly documented at this point, especially if the brainstorming is conducted in sub-teams.
11. A decision matrix should be created for each of the subfunctions. Among other considerations should be the ability for a concept to integrate with possible choices that the other subteams make. The chosen concept for each subfunction can then be presented to the entire team in a design review. The presenting subteam should be able to defend their choice (actually defend the values in their decision matrix) but should also remain open to suggested modifications from the rest of the team. If other team members offer significantly different concepts for that particular subfunction, then the decision matrix should be redone to consider the new ideas.
12. (For less experienced students) Before more detailed design can be pursued, the designers need to understand the materials available to them. As a group, quickly handle samples of each available part because the part descriptions may not be familiar. Allow free discussion as the parts are passed around and they think about what material might work for each part of their design.
13. At this point only the concept has been identified (e.g., arm with an elbow-joint and a gripper for a single ball), now the embodiment must be designed (e.g., select the materials, define lengths and other dimensions, choose fasteners, and choose the motor for each operation). Produce detailed sketches to be used for prototyping.
14. Prototype parts out of expendable or reusable material. The quality must be sufficient to simulate all major features of the design but you don't want to spend a lot of time using power tools and wasting good material. Several layers of cardboard can be laminated together with glue. Cutting parts from this laminate should be quicker than the real thing. If the parts are then wrapped in tape they can be quite strong. Try to use actual screws/rods at joints and simulate the actual movement as much as possible.

Marketing Team Objective:

The first week should focus on long-lead time items like ordering marketing materials (t-shirts, buttons). Interactions with persons outside of the team will also need to be planned (people visiting the team, and the team visiting the community). If a public venue is to be scheduled, the facilities will need to be reserved, speakers arranged, and invitations sent. Begin to schedule other student organizations to attend the competition.

These students should be aggressive in documenting the overall team's efforts (including the technical teams' efforts) since a lot will be developing quickly…and the story will need to be told in the Table Display, Presentation, and the Design Notebook. This includes a photo record, video record, and an ongoing written journal of all activities and decisions. There should be at least one marketing team member assigned the responsibility of collecting all the technical team's notes, sign-in sheets, models, etc., at EVERY meeting.

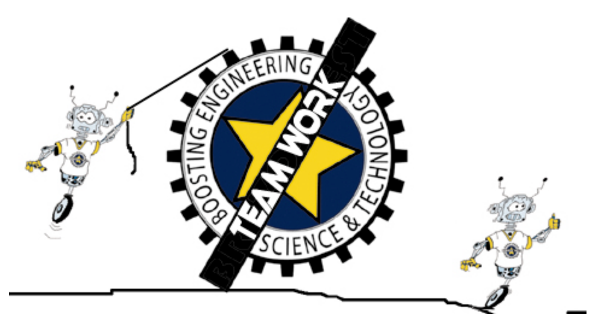
Week 3 & 4

Technical Team Objective:

The chosen solution is well developed now and the team needs to create formal production drawings based on successful part prototypes. Only produce actual components from drawings or detailed sketches. Don't allow design decisions to be made while cutting. Test assemblies as they become available and make sure to document the test plan and the test results. Electronics, motor mount, and shaft-couplers should be working by the middle of week 3. By the end of week 4 the major robot parts should be connected and driven by the remote control system. (The gripper will probably remain in production even at the end of week 4.)

The team can implement some standards at this point to greatly increase the chances of success on competition day.

1. All components should be as generic as possible while still serving their function. If the part only needs to be 9" long, but the stock material is 12" long and it is okay for the part to remain 12" long, Then do not cut the extra length off until absolutely sure that it won't need to be longer than 9". This allows the designers more flexibility during refinement. You'll be amazed how much of a difference three inches can make to a lever. Don't cut the metal rods until you absolutely have to. Metal rods cannot be stretched if cut too short and you probably have a limited supply of raw material. If you are not absolutely sure which motor shaft will be coupled to a component, then design in flexibility for either size.
2. All subassemblies should be as self-contained as possible. If the arm needs to be supported during testing, then integrate the support bracket into the arm design not in the robot-base design. This way the arm team can test their product without getting in the way of the robot-base team. This will also allow for a quick exchange if, for any reason, the arm needs to be replaced.
3. Install all the central electronics (not motors) on a single compact mounting plate that can be easily mounted in various positions or even relocated to another machine.
4. Design all components to be installed using minimal amount of hardware/steps possible. Avoid using hidden screws. The easier the robot is to maintain, the more bugs you'll be able to eliminate from the system in the last minute.



Marketing Team Objective:

Make detailed plans of what information needs to be conveyed in the marketing booth and team presentations. Make detailed sketches and work hard to fully integrate the team theme. Complete rough construction of the booth and populate with rough sketches and placeholders for the final information. Have most of the detail of the team presentation worked out. This is a good time to invite visitors to team meetings. If the team is mentoring other teams, this is a good time to help them with their BEST activities.

Week 5 (Before Practice Event)

Technical Team Objective:

A fully functional robot should be assembled by the end of this week including a working gripper. All documentation should be compiled into a design notebook.

The robot should be able to perform all desired tasks without breakdown or assistance. It is not necessary to have a polished performer. Yet there should be no doubt as to how any kinks will be worked out. If the robot is working at all then do not disassemble it for improvement until after practicing on the actual competition floor. Any desired changes should be noted on the construction drawings so they can be quickly implemented after the practice event.

The design notebook documentation should have been created at every step through the design process. All that remains is to create a narrative around these documents to thoroughly explain the design process that your team exercised. If a common standard for all drawings and sketches was not imposed early, then some may need to be redrawn to aid readability in the notebook.

Marketing Team Objective:

The team should practice their presentation and deliver it at least once to persons outside of the class. This delivery should be modified for the audience, but should contain most of the content of the final presentation. The placeholders on the booth should be mostly replaced with final versions of photos, drawings, and information narratives. If the marketing team has been actively collecting documentation throughout the process, then the notebook will only need a little polish. Work with the technical team to finalize the narrative in the design notebook.

Week 6 (Before Competition Event)

Overall Team Objective:

There are three priorities this week: driver practice, remove the many bugs found during practice, and marketing the product.

Technical Team Objective:

The technical team must be sure not to take any steps backwards. Do not disassemble the robot and leave it disassembled for long periods of time. Changes should be carefully planned to maximize the amount of operating time for driver practice and use by the marketing team. If you notice a part is prone to breaking, then manufacture a spare **and** try to design a robust solution to the problem. If the parts were designed according to the “generic” principles, then changes should not require complete disassembly. Prepare an emergency tool kit and part kit for use at the competition. Designers should monitor the driver practice (without interrupting it) to learn what systems might need to be tweaked.

Marketing Team Objective:

The marketing team has been engaged since before kickoff, but this is the chance to channel the bulk of the team’s energy in that direction. The marketing team should have already generated a prioritized “wish list” of ideas to market to the school, surrounding area, and on competition day. Now, other students can be assigned to the tasks to implement as many as time allows. This is when you’ll want to schedule school and community meetings. It makes for a busy week but you have a working robot and sponsors and kids like to see that. The team should strive for professionalism in all their work.

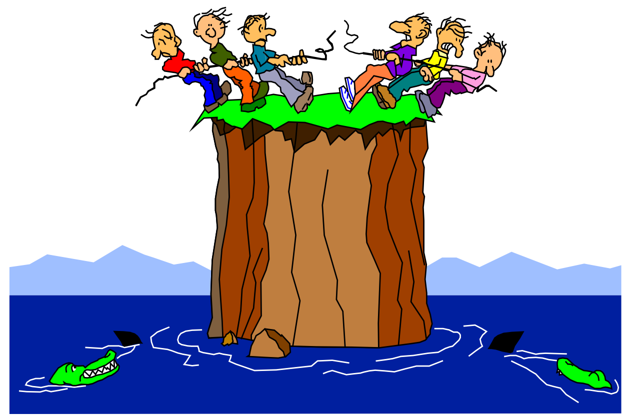
Education for the Coach and the Team

Teaming

Once roles are assigned, you should have a meeting with the leaders. Discuss the environment you want the team to have. Stress the need for POSITVE reinforcement and temper control. Talk about their previous teaming experiences and how to avoid problems they may have had. A clear set of expectations for the leaders and the other students is important. At the very least, have all your team leaders study the information in this section.

Characteristics of an Effective Team

Some factors which are considered essential to effective teamwork include:



- Spending time and effort initially to understand the task, generate ideas, and evaluate possibilities.
- Being aware of and allowing time for the stages of development of a team (i.e., Forming, Norming and Storming) as described later.
- An agreed clear purpose or goal of the team.
- Interpersonal skills to enable the team to work together to achieve the task and be fully involved in the process (i.e., an understanding of principles of effective team functioning).
- A task that can be subdivided, with each subtask having a defined outcome.
- Contributions by all individuals, so that the overall outcome is of a higher quality than if individuals worked independently.
- A commitment by all participants to contribute to the overall success of the team.
- An attitude where participants respect others' views and learn from one another.
- Working within agreed timelines.
- Team members trust one another and positive feedback is given to one another.
- Decisions are reached that EVERYONE supports.

Recommendations for Every Meeting

- Every team meeting should have a specified agenda…and the team should stick to it.
- Each meeting should have the following assigned roles:
  - Scribe: Records important information
  - Timekeeper: Controls the time spent on various topics and makes sure everyone's viewpoint is heard
  - Gatekeeper: Monitors discussion progress and lets the team know when off the subject
- Tardiness should be discouraged. Not only does it slow productivity it also undermines team unity.
- Team members should bring their information and assignment and understand the meeting purpose and objective.
- Track the team's progress in an obvious way like updating a milestone chart on the wall.
- Team members should be encouraged to:
  - Listen to each other and build on one another's ideas.
  - Ask for clarification whenever necessary.
  - Understand their follow-up assignment.
  - Give each other positive feedback.

Recommended Team Organizational Structure[8]

As with any large team project, it is paramount that an effective organizational structure be established. Not just on paper, but in practice. This is often easier said than done. Yet, the benefits of success will far outweigh the energy it takes to devise and implement a plan. An effective team will be:

- Less dependent on the coach, more likely to have a performing robot.
- Less likely to become frustrated with each other, more likely to finish the six-weeks with a positive experience.
- Less likely to suffer a last-minute chaotic dash to the finish line, and more likely to have time to step back and see the big picture.

One suggestion when you begin contriving your team structure is to distinguish the "role on the team" from the "skill group or specialist category." Let me explain. Consider a large automobile manufacturer. The engineers (or designers) are generally not the same people as the production personnel, administrative personnel, or the marketing group. They all have different skill sets. They are "specialists." But additionally, the engineers responsible for the engine design are probably not the same engineers responsible for the interior of the car. One serves the role of "Engine Designer" while the other is the "Passenger Compartment Designer." If you implement a similar scheme, not only will it aid your team dynamic, but it will provide the students insight into how companies function in the real world. As your robotics team grows in size, this dual classification becomes more justified.

The categories of **specialty skill sets** should generally represent the learning objectives for the entire robot integrated learning experience. But they should also facilitate design and construction productivity, especially early in the semester (when the students have not yet had a great deal of time to learn new skills). You might consider implementing a specialization scheme like the following (which utilizes four specialties):

- Marketing. Though skills in this category are not generally considered "technical" in nature, these students will serve an essential role in the BEST competition. These students should acquire the skills necessary to increase program awareness in the school and the community, encourage the team to pursue the real purpose of the BEST program, and compile a video and photo record of the team's progress. (Recruit outgoing students with good planning and organizational skills.)

- Technical Drawing. Technical communication skills (including drawing) are foundational in real world engineering. Without it a team cannot experience the benefit of synergy. Technical drawing will take a very long time to master, but some basic concepts will take the students a long way. All students in the team should be encouraged to develop their technical *sketching* skills and later technical *drawing* skills. But, students in this specialty must acquire visualization and technical sketching skills quickly. These students will likely want to serve in the role of designer in addition to their primary role as draftsman. (Recruit students based on their preexisting ability to visualize top/front/side views of real objects.)

- Production. Students with this specialization will need to master tool safety and become fluent in basic production operations including cutting and drilling. They must also be able to interpret the technical sketches produced by other students. The role that these students contribute as designers should be minimized (but not eliminated) as they will be very busy in prototyping and building. (Recruit students that already have experience with hands-on hobbies and are also mature enough to take safety seriously.)

- Method, Analysis, Documentation. These students will track (and police) the team progress through the official steps of the engineering process. They facilitate and participate in brainstorming design sessions. They will also engage basic analysis of designs using electrical and mechanics principles. Finally, they will commission and compile the necessary technical documents produced by other team members into a design notebook. (Recruit students with basic algebra skills and who have good organizational skills.)

[8] Adapted with permission, curriculum notes for integrating robotics in the classroom, Dr. Michael Wienen.

Assigning a specialty to each student will help the teacher direct in-class activities before or after the six-week long robotics program. It will also facilitate take-home assignments aimed at preparing each student to make a specific contribution to the team. During the six-week long robotics program, further assigning specific team roles will allow the team to make much quicker progress than if the team addresses every effort as a group. Example team roles are shown in the table below. Small teams are addressed in the left column. As more members are added to the team, the roles should be further dissected (as in the right hand column) to give individual responsibility to as many team members as is possible.

Example Team Roles[a]			
Students = 4	**4-8**	**8-16**	**16+**
Team Leader	Tech Manager	Body Project Manager	Body Project Manager
Team Member[b]	Designer	Body Designer	Body Designer
	Draftsman[c]	Body Draftsman	Body Draftsman
		Electronics Specialist	Electronic Specialist
		Engr. Analysis Specialist	Engr. Analysis Specialist
			Strategy Monitor
			Game Boss
		Gripper/Arm Project Manager	Gripper/Arm Project Manager
	Builder[d]	Gripper/Arm Designer	Gripper/Arm Designer
		Gripper/Arm Draftsman	Gripper/Arm Draftsman
		Production Manager	Production Manager
		Production Specialist	Production Specialist
		Kit Specialist	Kit Specialist
	Marketing Manager	Marketing Manager	Marketing Manager
	Booth Coordinator	Booth Coordinator	Booth Coordinator
	Notebook Coordinator	Notebook Coordinator	Notebook Coordinator
		Presentation Coordinator	Presentation Coordinator
		School Involvement Coord.	School Involvement Coord.
		Videographer	Videographer
		Photographer	Photographer
			Community Involvement Coord.
		Technology Manager	Technology Manager
		Webmaster	Webmaster
		DSP Programmer	Web Programmer
		Simulation Programmer	DSP Programmer
			Simulation Programmer
			Fundraising Coordinator
			Meeting Facilitator
			Event Coordinator
			BEST Liaison

a) Some roles require multiple students. Some students will probably serve two roles. For example, the Tech Manager might be the primary Draftsman. A Designer can also be a Draftsman if necessary. Do not allow a Designer to build his/her own parts.

b) Obviously very small teams cannot emulate the various departments in a large corporation. Each student will have a part in all the team tasks.

c) Companies differ on whether the Designer also serves as the Draftsmen. This is not preferred especially for younger students where it is challenging enough to learn the drafting rules without having to think about how to solve design challenges simultaneously. For novices it is best to separate them to allow the student to focus on the task. In this model, the Designer will produce the rough sketches from which the Tech-Drawing Specialist will create the neat drawings (either by hand or using CAD) that are used in production. This built in second-opinion can catch a lot of glitches.

d) Do not allow a novice Designer to produce a part that he/she designed nor allow them to *verbally* communicate the design to a Production Specialist. Insisting that they create sufficient written documentation to produce the object will develop their visualization skills and force them to think through all facets of the part (without subjecting their designs to the limits of their personal production skills). Even on a two-member team, have one student draw a part and the other student build it. Though experienced builders can sometimes "design on the fly," a novice should not even attempt to do so.

You should be able to review the many roles shown in the Example Team Roles table (above) and see how the four basic categories of specialty skills are represented in various team roles.

Stages in a Team Project[9]

Much taxonomy has been proposed to describe the general teaming experience. Regardless of the exact nature of the team activity, teams generally go through similar phases as they pursue an end goal. Being aware of these phases will help the team overcome challenges and attain high-productivity sooner. Teams should expect to go through the Forming, Norming, Storming, Performing, and Adjourning phases in-turn.

The forming stage represents the movement of an individual into the group-member status. Most team members will look forward to the beginning of their work. The team members' characteristics and suggested facilitator actions of this "feeling out" stage include:

Exhibited Team Behaviors:

- Hesitant participation tempered with optimism
- Organizational complaints and gripes common
- Some suspicion and fear of team situation
- Looking for sense of belonging
- Closely watching other team members' behaviors

Recommended Actions by Coaches/Mentors:

- Ensure team members get acquainted.
- Be sensitive to team members' needs.
- Provide clear direction and information.
- Give team simple tasks.
- Provide intensive "awareness" training.
- Provide training on team-building tools.

In the norming stage the team begins to come together. Conflict is substantially reduced as the team grows in confidence and begins to find that the team concept is working.

Exhibited Team Behaviors:

- Over-reliance on team leader/facilitator possible
- Conflicts reduced among team members
- Sharing and discussing become team norms.
- Greater team cohesiveness develops.
- Harmony among team members becomes common.

Recommended Actions by Coaches/Mentors:

- Provide less structure as team matures.
- Give team even more responsibility.
- Ensure team does not overly rely on any one member.

The storming stage may be a time when there seems to be little development and some problems between team members may emerge. Team members may need to focus on cooperating and ensuring that tasks are being done.

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[9] "*Working in Teams*"; Monica Berk and Sue Lintern; University of South Australia; November, 2002.

Exhibited Team Behaviors:

- Conflict between team members begins to show.
- "One-upmanship" develops.
- Concern over team versus individual responsibilities
- Continuing confusion about team members' roles

Recommended Actions by Coaches/Mentors:

- Continue to be positive and informative.
- Reassure team that current conflict is normal.
- Deal openly with conflict.
- Give team more responsible tasks.

The performing stage is when the team effectively engages the task for which it was created. As the team continues to work together, the personalities of team members and their contributions to the team are taken more for granted. While team members may be occasionally replaced, the team has become self-functioning. The team routinely defines and solves more difficult issues.

Exhibited Team Behaviors:

- Intense loyalty among team members develops.
- Teams may mask individual dysfunctional members.
- Teams can become competitive with other teams.
- Teams need greater information.
- Teams become more innovative.
- Team members become more confident.

Recommended Actions by Coaches/Mentors:

- Ensure team's information needs are fulfilled.
- Ensure that the team celebrates its successes.
- Encourage team toward continued growth.
- Ensure new team members are welcomed into the team and brought up to speed.
- Encourage team members to rotate roles.
- Reduce your involvement as team grows.
- Continue to foster trust and commitment among team members.

Eventually, the adjourning phase will come and the facilitator should not dismiss some simple cautions:

- The ending of any group or team needs to be acknowledged so you can have a sense of completion and be ready to move on. Where teams have worked well, and the outcome has been successful, you might be reluctant to finish because working with others has been such a rewarding experience.
- When outcomes have been disappointing, you might want to finish quickly without going through "ending steps," which may leave some members with feelings of "unfinished business."
- Ending Steps:
  - Be clear about when the last meeting is and that it is an important time for all team members to be present.
  - Ask the question, "What has been accomplished by this team?"
  - Discuss what went well, what was learned for application in the future.
  - Make clear statements about the end of the team, eg., "after our team has finished, wound up, concluded…"
  - Talk about who is responsible for any reports and where all members can gain access to copies of the report.
  - Organize a final event.

Teaching Team Skills to Students

More so than most skills, the ability to work as a team is probably best learned by experience. Even so, our ability to learn by experience is accelerated when we have an intentional taxonomy in which to organize our experiences. Regardless of the age of the student, expose them first to brief descriptions of various roles in teams, possible pitfalls of teams, and benefits of working in teams. Then engage them in some team-building exercises. You can find some teaching aids and team-building exercises in the Example Documents section. Teach them everything you have learned in the previous sections regarding Teaming.

The Design Process[10]

Over the years, many people have tried to define exactly what "Design" really means. A quick Internet search will reveal a vast number of definitions, not just in "Engineering" circles, but across all types of creative disciplines. The shear number of definitions tells us two immediate facts. First, that design is so commonplace that everyone has some familiarity with it. Second, it is unlikely that we contrive a thorough yet succinct definition that makes everyone happy. Feilden[11] proposed a very good definition:

> *Mechanical engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with maximum economy and efficiency. The designer's responsibility covers the whole process from conception to the issue of detailed instructions for production and his interest continues throughout the designed life of the product in service.*

The more experience a designer has, the more he or she will appreciate the nuisances in Feilden's definition. A novice is likely to have more appreciation for the simple definition offered by Archer[12] in 1964:

> *Design is simply a goal-directed problem-solving activity.*

Note one thing that is conspicuously absent from both these definitions. Neither suggest that a design activity necessarily implies a "formal disciplined" approach. A formal approach is NOT necessary for "design," but it certainly helps. **In fact a formal problem solving approach is the foundation for all engineering disciplines and is arguably the single most important thing that a student can take away from the BEST experience**.

Please, please, please convey to your team the importance of following a disciplined design process when solving complex problems. If they learn it, it will benefit them the rest of their lives even if they do not pursue engineering, science, or technology. Design can never be reduced to a **guaranteed** procedure that if followed will yield the optimum solution. However, following a formal procedure has been shown to greatly increase the chances that the Engineer comes up with a good solution to the problem he is facing.

Many Alternative Methods

There are many different ways to distinguish the various steps involved in engineering a product. In this section, four methods are presented just to show how different engineers organize their efforts. It is hoped that the inclusion of these varied opinions will call attention to some common ideas that your team should think about.

James H. Earle described the following six steps, which are easy for beginning designers to understand. His textbooks[13] are widely used in freshman level college classrooms:

1. **Problem identification**. The source of the real problem is probably deceptive.

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[10] Adapted with permission, curriculum notes for integrating robotics in the classroom, Dr. Michael Wienen.

[11] Feilden, G.B.R., "Engineering Design, Report of Royal Commission," London: HMSO, 1963

[12] Archer, L.B., "Systematic Method for Designers, London: Council for Industrial Design," reprint 1964

[13] Engineering Design Graphics, AutoCAD; James H. Earle; Addison-Wesley Publishing; 1992

- It is important to clearly define the problem before considering any solutions.
- This step involves describing what a solution must do, define constraints, and compile demands/wishes that are imposed.
- Data is gathered that might affect marketing, help prioritize the "wishes," or clarify unknowns.

2. **Preliminary ideas**. The more different ideas you generate, the better your final solution will be.
   - The team should brainstorm to generate ideas.
   - Make sure to preserve ALL the ideas in notes and sketches.
   - Research existing or past designs.
3. **Refinement**.
   - Choose the "better" ideas and create scaled drawings to determine the physical properties of the proposed solution.
   - At the same time determine what the critical elements of each design will be.
4. **Analysis**. This is where "science" meets "design," this is engineering.
   - This usually involves a lot of calculations that are taught in technical courses, but it begins with basic physical principles that are taught in middle school science.
   - These calculations are actually "mathematical models." Computer simulations are based on mathematical models. Physical models (like testable prototypes) are also very helpful.
   - Things we are interested in at this point:
     - ⇒ function....does it work?
     - ⇒ human factors...is it user friendly?
     - ⇒ product market...will it sell?
     - ⇒ physical specifications...limitations?
     - ⇒ strength...will it last?
     - ⇒ economic factors...is there a profit?
5. **Decision**
   - There are many tools to help make the decision, but somehow the single "best" design is identified.
   - Management should work very hard to ensure that the decision is unbiased and intelligent.
   - Implement a mathematically based "Decision Matrix."
6. **Implementation**. Production will require thorough working drawings, specifications, and instructions from the design team since it is generally different people that build the product from the people that designed it.

Shigley and Mischke[14], (page 6) also present a method for beginning designers to follow. They use different terms and emphasize slightly different things along the way. However, you can see the similarities to Earle's method even at first glance.

1. Recognition of a Need
2. Definition of the real problem
3. Synthesis of ideas
4. Analysis and Optimization of ideas
5. Evaluation of chosen solution
6. Presentation of final solution

Pahl and Beitz[15], (page 40) used the following **general phases** of the design process. They then proceed to describe many additional steps in each of the phases along with a fairly elaborate approach for expert designers to consider.

1. Clarification of the Task (e.g., a worker must have access to the second floor gutters on a house.)
2. Conceptual Design (e.g., we will provide something solid for the worker to stand on.)
3. Embodiment Design (e.g., we will provide a lightweight, easy to relocate structure.)
4. Detail Design. (e.g., structure consists of welded aluminum runners and rails…we'll call it a ladder.)

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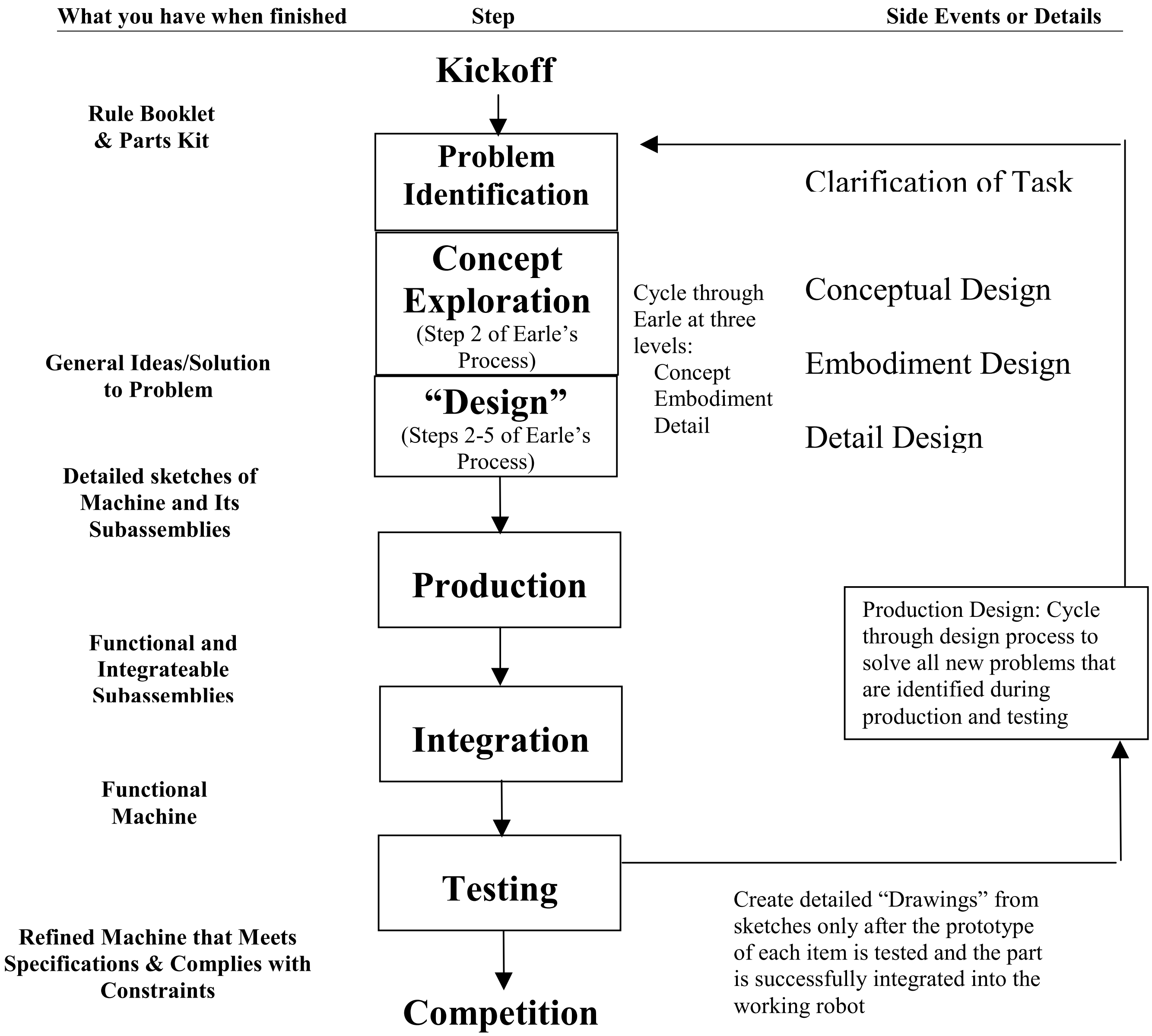
[14] Mechanical Engineering Design; Joseph Shigley and Charles Mischke, McGraw-Hill; 1989
[15] Engineering Design, A Systematic Approach; G. Pahl and W. Beitz; Springer-Verlag; 1988

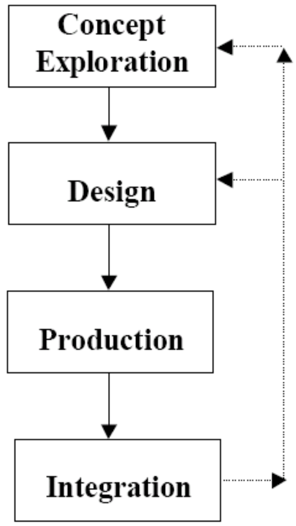
BEST Project Life Cycle[16]

The project you are about to engage goes beyond simply "designing" a robot…it must also compete. The following diagram illustrates how the process that most people call "design" fits into the overall product-development life cycle and how it is sandwiched between the BEST kickoff and BEST competition days. The most difficult part of the block diagram is the interplay between the Pahl/Beitz method and Earle's method that is represented in the two blocks "Concept Exploration" and "Design." The essence is this…in each **phase** of design (Conceptual, Embodiment, and Detail), the designer generates, refines, and evaluates possible solutions but the output varies depending on what **phase** he is in. The result of conceptual design is a general concept. This general concept is the seed that the embodiment phase turns into a specific form. The details of the form are then worked out in the detail design phase.

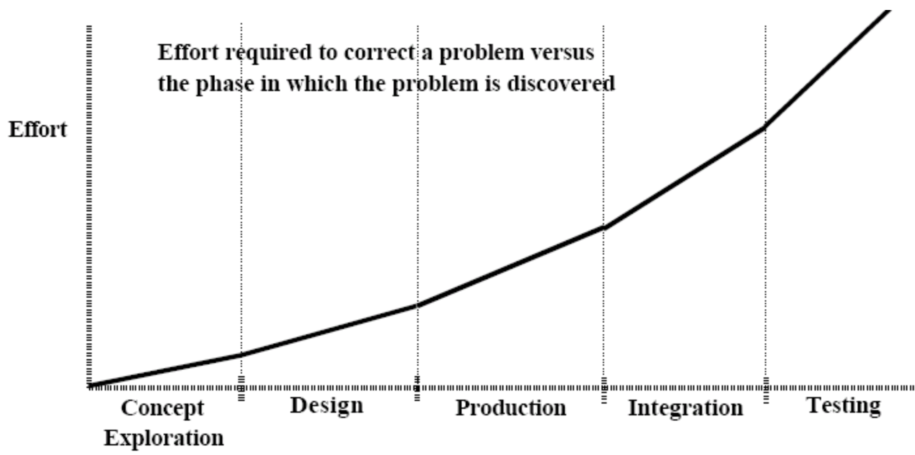


[16] This block diagram and the discussion on the following pages is adapted from "*An Overview of the Development Process*" by Garth Connelly of Texas Instruments.

It should be noted that the flow is normally cyclical among phases. For example, a team might leave the production phase then realize during integration that a subassembly will not function as desired. The team might reenter the design phase or even the concept exploration phase depending upon the extent of the problem.



Past decisions are always fair game for reconsideration when new information is discovered. In fact, one of the hardest things for a designer to overcome is a bias towards or against an original idea conceived early on. The following graph illustrates the need for development of a robust design early in the development process.



It is the coach's responsibility to help the team weigh the benefits of reconsidering a past decision versus the time that it will cost the team. It should be obvious that time and effort spent in the beginning of the flow will save time and effort over the course of the development process.

Problem Identification

Don't forget that the perfect solution to the wrong problem is not necessarily of any value to the customer. This phase begins with thorough research of the customer's specifications and constraints. Practically speaking, each team member should understand the details of the BEST game rule booklet. A general statement of the need should be created without regard to any potential solution to the problem. Accompanying this general need statement are lists for: the limitations or constraints that the final design must adhere to, the wishes that the team would like the design to fulfill, and a thorough description of the environment that the solution must interact with. The next step is to establish a "function structure" and search for possible solution concepts.

Concept Exploration
This section describes a simple procedure for your team to define a "function structure" and list of possible solution concepts. Once the specifications and constraints are understood, break the team into small groups. Each group should have an assigned recorder and "leader." The leader's role is more that of a "policeman" than a captain. He/she simply makes sure the rules of brainstorming are followed. The recorder simply makes sure that someone documents every idea.

The output of each group's brainstorming session should be a list of possible solutions to the problem…but only in very general form. For example, let's say that the customer wants "a vehicle that will carry passengers over land." The only apparent constraints for this simple example are that the vehicle must carry more than one occupant simultaneously and do so safely. Normally a person's list of ideas might be limited to things resembling an automobile. But given the specifications and constraints, we are confident that there are many other eligible solutions. The point of breaking the team into several groups is to draw on the innovative synergy of each group while not inherently restricting the solution set to those offered by the most vocal student in the class. A leader will emerge in any group (and that leader may or may not dominate the discussions). Having several groups will allow more students to have a voice.

The team as a whole has drafted an overall function, or problem statement, in the Problem Identification step. But each group should now break the overall function of the machine into smaller subfunctions. This is known as "functional decomposition." **While decomposing the problem, resist the temptation to make sketches**. Instead, give detailed descriptions of each function. This should prevent "etching" of any one potential solution into the team's collective "mental drawing board." In the case of the vehicle example, the subfunctions might include a method of propulsion, type of mobility, a means to protect the vehicle's occupants from the elements, and so on.

Each group then brainstorms solutions to address each of the subfunctions. Though many of the ideas will address several subfunctions simultaneously, occasionally an independent system will arise. Only if the group is free of preconceived ideas can they begin thinking "outside of the box." In our example, solutions that involve vehicles with **other** than four wheels, seats, and an engine will begin to evolve. Each group can either return to the class with their "chosen" solution concepts, or the entire class can consider each and every one for their worth. Either way, the decisions should be based on a decision matrix of some sort.

Suppose that three small groups brainstormed ideas and selected the following ideas to present to the class:

	Propulsion	***Mobility***	***Passenger Housing***
Group 1	Sail	Runners	Carriage
Group 2	Motor	Tank tracks	Seats with overhead cover
Group 3	Fans	Bed of compressed air	Cabin

Group 1's solution is limited to operating in a windy, slick-surfaced (e.g., icy) environment. Group 2's solution could operate wherever group 1's would and in sand, mud, on concrete, and so on. Both are limited to moving in contact with the ground. Group 3's solution potentially satisfies the customer's requirement to carry passengers over land from one point to another, yet it is capable of doing so over generally level terrain and even water. There are significant tradeoffs associated with the use of each solution. For example, each solution lists a means of propulsion that requires wind, battery power, or fuel. Which of these resources is readily available to the customer for powering the vehicle? Once each group has settled on their general solution and their decomposition, they should collectively decide on the final solution to address each subfunction (refer to the Decision Matrix section). It might turn out that one group's idea for a subfunction works well with subfunctions from another group or something else altogether. Maybe removable wheels on the sled would meet the requirements and still beat the hovercraft solution in compliance to some other constraint; namely budget and materials available. The team's general solution concept for each function is the output of the concept exploration phase.

Design

This phase begins with a clear understanding of the team's approach to solving the problem. The chosen conceptual solutions must be transformed into a detailed design for the machine and its subassemblies. This is the time for creation of detailed sketches. Using the combined runners with wheels solution, the team must design the wheels, runners, carriage, and so on. Each subassembly must be designed within the constraints and such that each will function and fit together to form the machine. A robust design is one that at least has the following characteristics:

- **Understandable** - Can and do team members understand and communicate the design? Can the machine be operated without an extensive training period?
- **Simple** - Is the design simple in its production and operation? Does the production require special tools or processes that are unavailable to the team during the actual competition?
- **Reliable** - Does the machine's design make it prone to breakage or functioning only in the best of conditions?
- **Changeable** - Can any subfunction be redesigned without changing the overall design of the machine?
- **Makeable** - With the tool and facility resources the team has, can they produce the subassemblies? Do the subassemblies easily interface with one another?
- **Maintainable** - Can a part or subassembly on the machine be replaced quickly and easily with limited tools in the heat of competition? Can parts be accessed without dismantling the machine?
- **Strategic** - Does the machine's design allow it to be used offensively and defensively?
- **Fool-proof** - Is the machine inherently tolerant of operator mistakes? For example, does it automatically align itself with the goal?

The output of this phase should be a detailed design of the machine and its subassemblies.

Production

This phase begins with a robust design. Machine subassemblies are produced according to the detailed design. During production, attention must be given to available materials. This is particularly true if prototypes are developed from the same material stockpile as the final machine. A comprehensive production plan should be thought through. The production plan must consider all the parts that will be made and schedule the labor and materials that will be allocated to each part. Parts that will require extended testing time should be produced first (assuming that they can be tested independent of the other subassemblies). Parts surrounded by a great deal of uncertainty should be prototyped before less significant features are produced. Also, there are some parts that you know will be needed regardless of the outcome of any remaining design decision (like shaft couplers and motor mounts). These items should be produced as early as possible to facilitate immediate testing as subassemblies become available. Finally, don't make the mistake of running out of material simply because a wheel was cut out of the middle of a board instead of cutting it out of the corner. Such mistakes can be avoided if a good production plan is in place.

Avoid becoming fixated on aesthetics of the machine at this point. Do not discount appearance altogether, but remember that it is below functionality on the list of priorities. The output of this phase should be several subassemblies, each performing some subfunction(s) of the machine and each fitting together per the design. Because it is unlikely that all the subassemblies are completed simultaneously, they should be designed in a way that some testing can be performed independent of the other systems.

Integration

This phase begins as interacting subassemblies become available. The subassemblies are put together and made to function as one machine. For example, wheels are attached to the axle and the runners attached to the carriage. Connect the drive train between the engine and the axle. This is where many flaws in the design will materialize. The team may find that the wheels don't stay attached to the axle, the drive train doesn't provide enough torque to turn the wheels, or the electronics interfere with the arm rotation. This is NOT the time to abandon big decisions and go back to square one. Develop a plan that permits a quick recovery from the problem **with as little rework of completed and functional subassemblies as possible**. Remember, the team's time and materials are becoming more limited as time progresses. The output of this phase should be a working machine that is ready for testing.

Testing

This phase begins with a working machine or independently working subassemblies. At this point, it is wise to have a small portion of the playing field constructed and ready for use in testing of the machine. Multiple operators in various environments should conduct testing to cover as many variables as possible. The results of the test will help the team polish their competition strategy. During competition is not the time to learn about controlling the machine or its special quirks! The testing environment should simulate the competition environment as much as possible. The practice-day competition is the perfect opportunity to test both machine and operator.

Technical Resources

Brainstorming Guidelines

Creative engineering design is a two-part process: divergent thinking and convergent thinking. As a designer searches for solutions to the problem at hand, he/she must strive to consider the broadest possible range of solutions. As the designer's mind opens to different creative possibilities, divergent thinking is occurring. During refinement and analysis, the engineer will rely on convergent thinking to narrow the set of possible solutions and hopefully zero in on the best possible solution. However, the designer can only be confident that the chosen solution is the "best" within the set of solutions that were initially conceived. Therefore, the engineer owes it to the customer to think divergently as much as possible and thereby maximize the chances of finding the overall best solution. Though such creativity can arise very unexpectedly and unintentionally, this is no way to plan to meet project deadlines. There are some intentional methods that can be utilized to increase the chances that the designers will come up with many creative solutions to consider. One technique that is commonly known is "brainstorming."

Brainstorming is a group process in which all members contribute ideas "simultaneously" and "spontaneously." Yes, an individual can engage brainstorming alone. However, the implied goal of brainstorming is to achieve synergy and compile more varied ideas than if all the team members would have produced ideas by themselves. It is more than simply compiling the individual lists into a whole. Group members should seek to use the ideas of others as seed to explore new solution spaces. The term, brainstorm, embodies the state of excited and explosive mental activity. Free outbursts of creative thinking are the goal. Yet, without some guidelines many good ideas will get lost in chaos.

Step 1: Identify the topic(s) to be brainstormed. (A specific problem statement should have already been created.)

Step 2: Review the rules before starting the session:

- Focus on one specific topic for the duration of the session.
- All team members participate in turn.
- Only one idea per person per turn (additional ones can be jotted down quickly less they be forgotten).
- Accept all ideas at face value. Do NOT edit, discuss, evaluate, reinforce, criticize, ridicule, or belittle any idea during the brainstorming session. The more outrageous an idea, the better (pigs CAN fly).
- Record all ideas generated (try to avoid pictures or sketches as much as possible but use verbal descriptions instead).
- A member may elect to "pass."
- Continue until all members "pass."

Step 3: Begin the brainstorming session.

Tips:

- During the session, emphasis should be on quantity of ideas and not the quality of ideas.
- To record all ideas without slowing down the production of ideas, use a tape recorder. But check it often to make sure it is working and the group is not losing ideas to static.
- Look for solutions that employ entirely different physical principles. For example, if all the ideas seem to relate to an electric motor, then initiate a second session. However, insist on non-electric motor solutions (pneumatic, manual power, hydraulic, etc.).
- Look to nature for examples. Ever notice how similar Velcro is to "grass-burs?" That's where they got the idea!
- Occasionally, encourage creativity with silly solutions like "train earthworms to carry the balls towards the goal." True, earthworms are not in the materials list. Yet, it might remind someone else in the group of how cilia work together to manipulate air stream contaminants out of the trachea and bronchial tubes leading down into the lung…hmm maybe we could have a series of small actuators instead of one big one?

Making Decisions with a Decision Matrix[17]

Though we love the freedoms available within a Democracy, the democratic process is not a good way to make engineering decisions. Only the least significant decisions should be made using a popular vote. Using the "majority rule" WILL undermine your team (as is evident by the political state in our country). Even if your team experiences success, it will do so at the expense of some individuals. Designers are notoriously biased to their own ideas and will likely be personally offended when their ideas are not adopted. **Always seek consensus…reach a decision that everyone can fully support by removing the personal association as much as possible.** One way to make decisions less "personal" is to employ decision matrices. Though a designer is likely to be personally attached to a particular idea, it is likely that he/she can view individual elements of the design matrix without significant bias.

In a decision matrix, one records the expected performance of each design alternative in each of the important performance categories (the Factors). The designs with the highest tallies are expected to be the better overall performers. In the following example, a team has identified six alternative design concepts and wants to rate them. Each row represents one of the alternative designs. The team in this example has defined seven factors that are thought to be important in the decision (Factors A-G). These factors were contrived by listing the pros and cons of each idea (and many other "lesser" ideas) and by considering the original function structure defined in the problem identification phase of the design process.

Example Decision Matrix

Design Alternative	Important Factor in the Decision							
	A	B	C	D	E	F	G	**Total**
1	6	0	6	0	16	14	5	47
2	3	12	6	24	16	14	5	80
3	0	24	6	24	16	0	5	75
4	6	12	0	12	0	7	10	47
5	0	24	0	24	8	7	10	73
6	3	24	0	24	8	0	5	64
Max	6	24	6	24	16	14	10	100

Factor Descriptions:

A. Design allows for specificity of game piece selection
B. Design is independent of driver skill
C. Design has ability to protect pieces from other teams
D. Design has potential for high speed scoring
E. Design facilitates predictable scoring outcome
F. Design easily handles each game piece type
G. Design is simple (leads to robust design)

<u>Steps in implementing a Decision Matrix:</u>

1. Narrow the design alternatives in informal discussions. Favored traits can be combined to form fewer-better design alternatives.
2. Generate a list of independent factors that effect how well the design will address the original problem statement.
3. Specify the relative importance of each factor by assigning it a maximum-point value (last row in the matrix). The sum of all these factor weightings should be 100.
4. Rate each design in each factor category. Only use high, medium, low values in each cell of the matrix. Engage team discussions for each cell until consensus is reached.
5. Designs with the highest totals should be further developed and their cell values scrutinized. Look for a natural break in the total scores. (In the above example design 2, design 3, and design 5 are candidates for further consideration.)

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[17] Adapted with permission, curriculum notes for integrating robotics in the classroom, Dr. Michael Wienen.

6. (If necessary to further separate the final candidates) Specifically compare the top three alternatives to each other. In each category, assign a "high" to only one idea, "medium" to only one idea, and "low" to the remaining idea. Eliminate ties in each category by slightly modifying each idea with traits from other designs if possible.

Notes on interpreting the matrix results:

- As you can see in the example decision matrix, if each of the options has any merit at all, then the final results can be very close.
- Don't think of the results as an absolute decision, but rather as a distinction between the poorer and better ideas.
- Certainly, the lowest scoring ideas are eliminated while none of the top few ideas should be casually dismissed.
- Your design intuition might still be the most important factor...

Where should we apply a decision matrix?

A decision matrix should be employed for any complex decision that involves several alternatives and multiple factors that affect the decision.

In early phases of the design process…

A matrix can be insightful even in the problem identification phase of the design process. As you investigate the challenge, you will identify needs and wishes. A concept is only eligible if it addresses ALL the needs. However, the wishes can be compromised. An initial general problem statement and function structure is created (e.g., "Get many points"). Then **conceptual** solutions are brainstormed and categorized to form design alternatives. At this phase the "design alternatives" are more like "strategies":

1. Pick-n-place one at a time
2. Pick-n-place many simultaneously
3. Pick-n-place continuously
4. Non-possession one at a time
5. Non-possession many at a time
6. Non-possession continuously

When these alternatives were compared in the design matrix (on the previous page), the team was able to revise their original problem statement, "get many points." The new, more specific, problem statement is "Design a pick-n-place machine to transport all sizes of balls and place in all three scoring areas in a multi-ball or continuous fashion."

In the embodiment phase of the design process…

A more specific problem statement will generate a more narrow set of possible solutions. The deciding factors will also be more specific. At this stage, the team might be trying to decide between three alternatives for mounting a motor on the machine. Alternatives might include use of strapping tape, building a mounting plate from sheet metal, and creating u-bolts from threaded stock. The factors would include easy to construct, easy to install, easy to relocate, low-interference with other parts.

In the detail design…

Should a decision matrix be employed when trying to finalize dimensions, make material selection, or when choosing fasteners? Probably not given that our final product is simply a learning experience. However, if time allows it might make a good learning tool to engage an official matrix when choosing between wood screws, metal screws, duct tape, and glue in a given application.

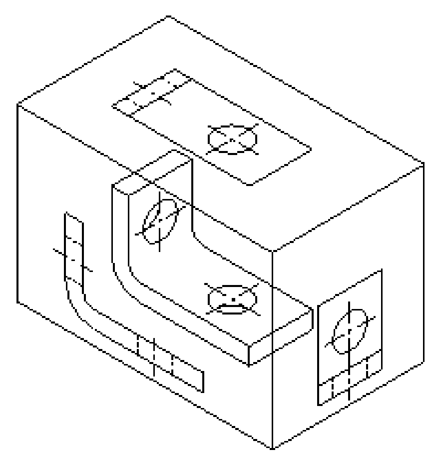
Technical Sketching and Drawing[18]

Engineering documentation heavily relies on Technical Sketching and Technical Drawing. The fundamental goal of both is to document an idea. However, the applications and rules for each differ significantly. Not all ideas are worthy of spending hours to document them on a CAD system. However, **just about all ideas are worth the 30 seconds it takes to sketch it**. You will be surprised how often you come back to an idea that you previously dismissed...whether you incorporate the whole idea or just a part of it. If you do the brainstorming process correctly, then even an elephant won't be able to remember all of the ideas that are generated (not that he could describe them to you very well anyway).

Technical Sketching:
The ability to sketch helps in the design process, but if you are working with a team it becomes essential. The guidelines for technical sketching are as follows:

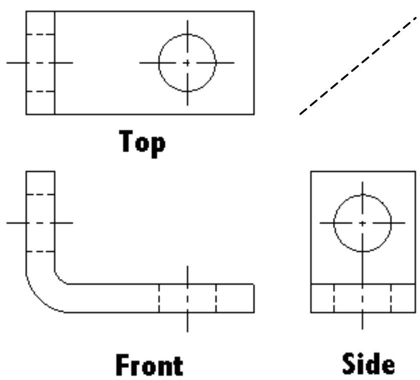
- Sketching should be a **rapid process** that aids the thinking process.
- If the sketch is not **clear and detailed** enough to convey the idea to another person, then the designer probably has not developed the idea enough.
- Representing a 3D world on a 2D sketch is best accomplished by following an established convention. Stick with **orthographic, or multiview projection**, as a way to clearly show every side of an object.
- Sketching is a **freehand technique** that does not use instruments or straightedges. You can violate this rule if you want, but it will slow you down. It is better to develop the skills that allow you to sketch without instruments or straightedges.
- Two types of sketches should be mastered, **standard three-view sketching and isometric sketching**.

Standard three-view sketching (orthographic projection)
Imagine placing the object that you want to draw in a glass box. The box has six sides (top, bottom, front, back, right side, left side). These represent the six "principle" views. Think about what each of the six views would look like for the angle bracket that has been placed into such a glass box. Though it is possible to draw six distinct Orthographic Projection views of any 3D object, objects can usually be represented with a standard three-view projection (top, front, side). The views have been etched on the sides of the glass box to help you visualize them.



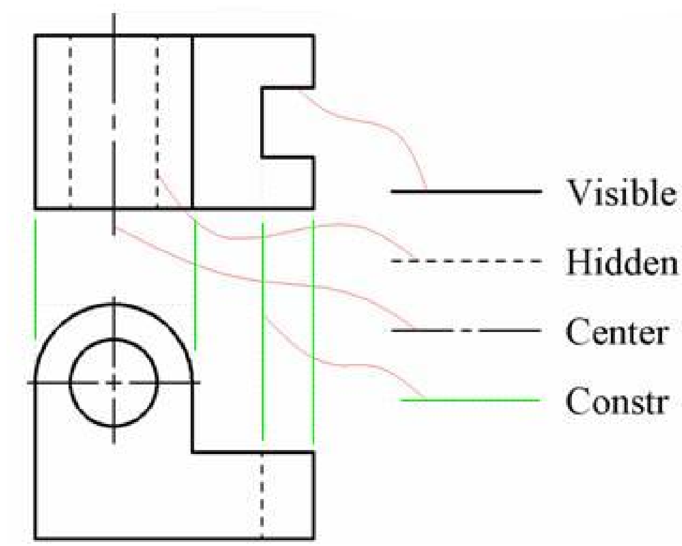
[18]Adapted with permission, curriculum notes for integrating robotics in the classroom, Dr. Michael Wienen. Images in this section are from lecture notes, *Introduction to Engineering*; College of Engineering, Texas A&M University, 1998.

To make it easier on the person creating the sketch, these views are laid out on a piece of paper following an established convention. (To be thorough, it should be noted that this discussion is using "third angle projection.") Typically three views are sufficient to convey all the pertinent information about the part. When this is the case, the top, front, and side views are arranged as shown below. Note which view of the object is called "front," which is called "top," and which is called "side," respectively.



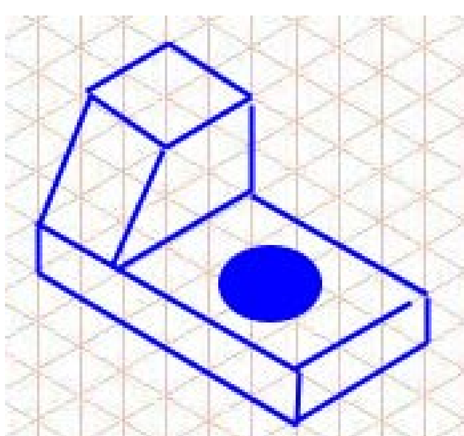
- Orthographic views should be aligned with each other (temporary lines can be drawn to show how each edge is lined up with edges in other views but these temporary lines should be erased when finished).
- The width of the part appears in Top and Front views.
- The height appears in Front and Side views.
- The depth appears in Side and Top.
- Height and width project directly between views.
- Depth must be projected via a 45 degree angle (shown as a dashed line that should be erased when finished)

Object features can be represented easily using special line types: visible, hidden, center, and construction lines. Visible lines are solid and bold. They represent features that are visible in the view with the naked eye from that particular direction. Hidden lines are dashed and indicate features hidden beneath the surface of the part. Center lines are used to indicate that the feature has a geometric center. While construction lines are lightly drawn lines used to aid the sketching process and should be erased when the sketch is complete.



Isometric Sketching

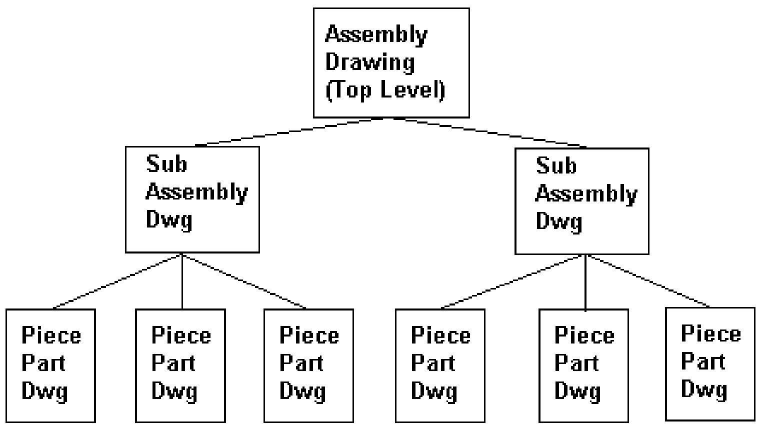
Three-dimensional objects can be represented in a single view called an isometric view like the one shown below. Note that such sketches are aided by the use of special grid paper.



The isometric view can be used to quickly convey the overall features of the part. However, it is difficult to convey the actual dimensions of the part. It is important to note that:

- Angles cannot be measured with a protractor in isometric pictorials.
- Circles are not round in isometric pictorials.
- If two sloping planes intersect each other, then each plane must be drawn separately.

Technical Drawing
Though sketches can quickly convey the shape of an object, the designer will eventually need to convey the more precise details of the design to the production crew. It is true that dimension callouts can be added to any technical sketches. However, if the design is adopted it is likely that the designer will want to take the time to formalize the documentation. Technical drawings can either be drafted by hand using a broad range of drafting tools, or can be created using Computer Aided Drafting/Design tools (CAD). There are two main types of engineering drawings that are common in the design process of a complex machine. They are "Piece Part Drawings" (or component drawings) and "Assembly Drawings." A Piece Part drawing shows the size, shape, material, and processes used to create a part that is used on a higher assembly. The Assembly drawing conveys the information necessary to assemble the piece parts into a working system. So, it will include a bill of materials that lists all piece parts and subassemblies needed to create the assembly along with assembly instructions or notes. A "Drawing Tree" can be helpful in identifying how the various parts are integrated into the whole system.[19]



Piece part drawings are created using orthographic projection and should contain the following minimum information:

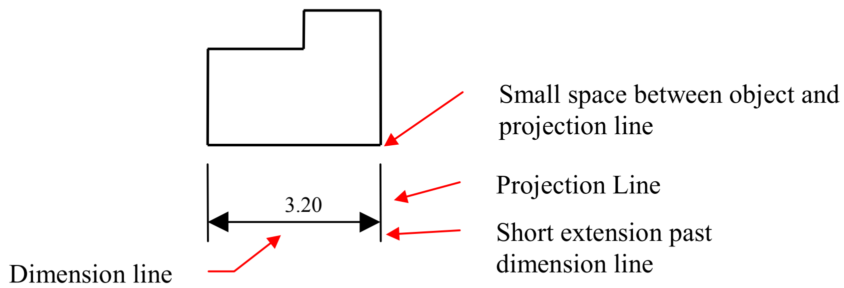
- Drawing title
- Date
- Designer's name
- Material used
- Enough detail and dimensions to build the part
- Change history (in industry, drawings are often revised over the years)
- Next higher assembly (where used)

Assembly drawings should contain the following minimum information:

- Drawing title
- Date
- Designer's name
- Bill of materials (parts required to build)
- Balloons pointing to each part on the Bill of Materials
- Assembly instructions
- Change history
- Next higher assembly (where used)

[19] The diagram and related discussion are adapted with permission, Chris Cormier, *"Engineering Graphics."*

A picture may be worth a thousand words, but without dimensions and callouts an engineering drawing is not worth much. An exhaustive discussion of established dimensioning conventions would be inappropriate here and in fact most tech-companies will have their own peculiarities. However, the fundamentals can be conveyed quickly in an example.



There are some very basic rules that should be followed:

- Dimensions should be placed on a drawing so that they are easily read. They are always placed **outside** of the boundaries of the object being described.
- Projection lines (sometimes called extension lines) are projected perpendicular to the object and they do not touch the object. They indicate the start and finish of the feature of interest.
- The dimension line is a continuous line and no other lines should be allowed to cross it. It can be broken only to insert the text of the dimension if this adds to the clarity of the drawing.
- Units of measure should be consistent on the drawing and indicated somewhere on the drawing. They do not need to be appended to every dimension…that would simply add unnecessary clutter.

There are many different types of dimensioning systems. You can find detailed guidelines by entering "engineering drawing" into any Internet search engine. Because the goal of dimensioning is clear communication, the simplest possible system should be employed. Dr. Richard E. Link at the U.S. Naval Academy has a thorough discussion that your students can study (see navy_dimensioning.pdf).

As previously indicated, the information conveyed in an engineering drawing does not stop at the physical dimensions of the part. We have included the required drawing format used by a manufacturing group for your reference (see quartic_drawingguidelines.pdf). After all, who would know better what is required than the people that have to actually build the parts?

Final Note:
The goal is NOT for students to become expert draftsmen. Technical sketching and drawing is essential for communicating engineering ideas among team members. The practice of creating sketches and drawings will help the students flush out the details of their designs.

Tool Safety[20]

Any person that is working with tools should be trained to use them safely. **Any student working with tools or around them should have a signed contract on file** that verifies that the parent is informed of the risk and believes that their student is mature enough for the responsibility. An example can be found in the Example Documents section). Sawing, drilling, grinding, and even hammering can produce sparks or splinters. Regardless of what tool you have in your hand, it can hurt you! Respect it for its capability…not just for what you plan to do with it.

Safe Shop Practices

- Require every person that enters the tool/construction area to be trained and certified on all the safety and emergency procedures. (Look in the Example Documents section for a sample safety test.)
- Restrict traffic around the construction area to essential personnel only.
- Enforce strict cleanup policies to avoid distractions and tripping hazards.
- Ear protection is not optional. It is proven that exposure to tool noise contributes to hearing loss.
- The key to power tool safety is FEAR! Always be RESPECTFUL (afraid) of that tool and what it COULD do if that really remote possibility happened. No tool is dangerous - only the person using it.
- Avoid circular saws, table saws, and band saws with students. There is nothing that is so critical on student-projects that it cannot be cut with a good jigsaw (saber saw) or scroll saw. If you really need a straight line, then use a guide on your jigsaw or a fence on your scroll saw.
- Make sure that all machines have start and stop buttons within easy and convenient reach of an operator. Start buttons should be protected so that accidental contact will not start the machine. A collar around the button 1/8 to 1/4 inch (3 to 6 mm) above the button is recommended.
- Train all users to use the proper tool for the job. It is important to know the difference between woodworking tools and metal working tools.

What should you do before using woodworking machines? [21]

- Woodworking tools can be dangerous if not used properly.
- Only use woodworking machines that you have been trained to use properly and safely. [If you don't know how to safely inspect a tool for damage, then don't use it. Never use an obviously damaged tool.]
- Read the owner's manual carefully.
- Make sure you understand instructions before attempting to use any tool or machine. Ask questions if you have any doubts about doing the work safely.

What safety procedures should you follow when using woodworking machines?

- Always wear safety glasses or goggles. [Safety guards on the cutting tools do NOT replace the need for safety glass or goggles].
- Wear dust masks when required.
- Wear hearing protection that is suitable for the level and frequency of the noise you are exposed to in the woodworking area. If you have trouble hearing someone speak from three feet away, the noise level from the machine is too high. Damage to hearing may occur.
- Use gloves to protect hands from splinters when handling wood but do not wear them near rotating blades and other machinery parts where the gloves can catch.

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[20] Adhering to the suggestions in this section CANNOT guarantee that no injuries occur. Please consult with your school district and adopt their official safety practices. It should be noted that Michael Wienen is NOT a certified safety officer and neither he nor BEST Robotics Inc. can be held responsible for student safety regardless of the safety practices that your team adopts.

[21] Woodworking Machines: General Safety Tips, Canadian Centre for Occupational Health and Safety, 1999. Reproduced with the permission of CCOHS, 2005. Comments by Dr. Michael Wienen and various online tool-safety discussion forums have been indicated in square brackets [ ]. Guidelines for "woodworking" machines are generally applicable to metal working machines. Always integrate the machine manufacturer's safety instructions into your shop guidelines and training sessions.

- Make sure the guard is in position, is in good working condition, and guards the machine adequately before operating any equipment or machine. Check and adjust all other safety devices.
- Make sure the equipment is properly grounded before use.
- Check that keys and adjusting wrenches are removed from the machine before turning on the power.
- Inspect stock for nails or other materials before cutting, planing, routing, or carrying out similar activities.
- Ensure that all cutting tools and blades are clean, sharp, and in good working order so that they will cut freely, not forced.
- Turn the power off and unplug the power cord (or lock out the power source) before inspecting, changing, cleaning, adjusting, or repairing a blade or a machine. Also turn the power off when discussing the work. [Unplug electrical tools when finished with their immediate use.]
- Use a "push stick" to push material into the cutting area. Jigs are also useful in keeping hands safe during cutting procedures. Keep hands out of the line of the cutting blade.
- Clamp down and secure all work pieces when drilling or milling. [Never allow a second person to hold the work piece. Jigsaws (saber saws) tend to bounce a lot, keep both hands on the saw and cut only on a solid surface. If the work piece is not clamped down while drilling, then the work piece tends to turn into an extremely dangerous helicopter blade.]
- Use good lighting so that the work piece, cutting blades, and machine controls can be seen clearly. Position or shade lighting sources so they do not shine in the operator's eyes or cause any glare and reflections.
- Ensure that the floor space around the equipment is sufficient to enable you to machine the size of work piece being processed safely without bumping into other workers or equipment.
- Woodworking machines should be fitted with efficient and well-maintained local exhaust ventilation systems to remove sawdust or chips that are produced.
- Electric power cords should be above head level or in the floor in such a way that they are not tripping hazards [and cannot get caught in the cutting tool].
- Keep work area free of clutter, clean, well swept, and well lit. Spills should be cleaned up immediately. Floor areas should be level and nonslip. Good housekeeping practices and workplace design will reduce the number of injuries and accidents from slips, trips, and falls. [Check the work area regularly, be it a work bench or an acre lot. Take the time to clean up the area before you start and after you finish. Don't leave tools out where unsuspecting persons could get hurt by them.]
- [Do not rush the tool or the project.]
- [When using a drill press or a drill motor to drill through a wood or metal surface, do not have carpet on your bench or on your floor. Carpet or fabric grabs the speeding drill bit so quickly – you become wound up in a split second. This warning also includes long hair and loose clothing.]

What should you avoid when working with woodworking machines?

- Do not wear loose clothing, work gloves, neckties, rings, bracelets, or other jewelry that can become entangled with moving parts. [In a nanosecond, clothing or hair can get caught in a tool and suck the operator into the path of the tool. Serious injury is almost guaranteed to follow. Long hair MUST be kept in a bun when using power tools. Do NOT rely on a ponytail to keep hair out of any power tool]
- Avoid awkward operations and hand positions where a sudden slip could cause your hand to move into the cutting tool or blade. [Never place a body part in the path of a tool and never push directly towards a working tool. If the tool slips, you don't want it to head suddenly towards you. If your hand should slip, you don't want it to move suddenly into the tool.]
- Do not remove sawdust or cuttings from the cutting head by hand while a machine is running. Use a stick or brush when the machine has stopped moving.
- Do not use compressed air to remove sawdust, turnings, etc., from machines or clothing.
- Do not leave machines running unattended (unless they are designed and intended to be operated while unattended). Do not leave a machine until the power is turned off and the machine comes to a complete stop. [Be sure to avoid injury when the tool is powered off but still in motion. Saws, drills, and similar tools can still wreak a lot of havoc if you encounter their un-powered but still spinning moving parts.]
- Do not try to free a stalled blade before turning the power off.
- Do not distract or startle an operator while he or she is using woodworking equipment.
- Horseplay should be prohibited. It can lead to injuries.

Soldering

A detailed guide to soldering electrical connections is provided as an appendix to this manual.

Robot Troubleshooting

A detailed BEST robot-troubleshooting guide has been compiled and is appended to this manual.

Technical Writing[22]

The act of generating an effective Technical Document lies somewhere between a science and art. We will not attempt to even summarize the body of knowledge that exists, but instead will offer some guidelines to get you started.

The overall goals of technical writing are:

- The document must be **accurate**. Your report must reflect the technical detail and results of your design.
- The document must be **clear**. This active pursuit begins with the document structure by including a good table of contents, abstract, strategic repetition, frequent subject headings, and tables and graphs to focus the reader's attention. Ease of understanding is further increased if the author uses simple language in direct sentences.
- The document should be **concise**. The author should make intentional choices to focus on the important (instead of everything that might be relevant) and filter out any information that is not essential.
- The document should be **coherent**. Make an active effort to provide a path for the reader. Emphasize relationships between sections. Subject development should be logical. Ensure that the context is explained while also giving the reader a preview of what follows.
- The document should be **appropriate** for the audience. Since a technical document has a specific purpose or goal, it also has a specific audience. The word choice should consider who will be reading the document and their background (i.e., is the reader an expert, a layperson or somewhere in between).

Steps to creating a technical document:

1. Identify the document's purpose and audience.
2. Collect your information.
3. Outline the document.
4. Plan and sketch out significant graphs and tables.
5. Write the first draft section by section.
6. Revise the outline and reorder sections as necessary.
7. Ensure each section leads to the next.
8. Check that each paragraph has a clearly-defined topic.
9. Verify that the document as a whole is accurate and each piece of information is both relevant and important.
10. Edit for grammar and style.

Content of a Technical Document (Specifically, the BEST Design Notebook)

There are some generally accepted guidelines that can aid the readability of the document. The final form and content of the document will vary based on the specific purpose and audience. The BEST Design Notebook is often assumed to be a "Design and Feasibility Report" because the team must describe their proposed solution to a specific problem. However, the purpose of the notebook (as stated in the sample guidelines) suggests more of a "Research Report," which elaborates on the methodology of an investigation. Teams should probably investigate both types of reports when planning their notebook.

[22] Recommended for further reading, "The Mayfield Handbook of Technical and Scientific Writing" online; Leslie Perelman, James Paradlis, and Edward Berrett.

Remember that the goal isn't to create a document that consists of all the "right" sections. The goal is to create a document that appropriately addresses its purpose.

Design and Feasibility Report	**Research Report**
Informative Title Page Abstract Summary of Recommended Design	Informative Title Page Abstract Executive Summary Table of Contents List of Tables/List of Figures (optional) List of Terms (optional) List of Acknowledgements (optional)
Introduction and Context Design Criteria Recommendation and Alternatives Elaboration of the Design	Introduction Background Theory Design and Decision Criteria Materials and Apparatus Procedure Work Plan Results Discussion Conclusion Recommendations
Conclusion	References Appendices Indeces

General tips:

- Ensure that paragraphs are coherent.
- Use active voice to enhance clarity.
- Use simple and direct sentences and eliminate unnecessary words.
- Combine repetitious sentences to be more concise. (This does not mean to eliminate forecasting.)
- Use precise descriptive words.
- Don't neglect to define the problem you are addressing as well as the purpose and scope of the document in the introduction.
- Graphs and Tables should be numbered consecutively and have an informative title and caption. The trends and conclusions drawn from them should be spelled out in the narrative (don't assume that the reader will draw the same conclusions as yourself). A picture may be worth 1000 words, but like a technical drawing without dimensions, a picture in a technical document is not worth much without an explanation in the narrative.
- Do not expect every reader to consult the Appendices. If information is important to every reader, then it should be in the main document.
- Use somewhat consistent fonts and do not require the reader to use a magnifying glass to extract information from graphs, tables, and pictures.

How to Successfully Engage the BEST Award

Winning the BEST Award is considered the highest achievement any team in the competition can accomplish. First, second, and third place finishes will be awarded. This concept recognizes that inclusiveness, diversity of participation, exposure to and use of the engineering process, sportsmanship, teamwork, creativity, positive attitude and enthusiasm, and school and community involvement play significant roles in a team's competitive experience and contribute to student success in the competition beyond winning an award.

How well your team does in the BEST Award competition is the most prominent indicator of whether or not you are maximizing the potential impact of the BEST program at your school. Yes, official participation in the BEST Award competition is optional. Yet, the implicit goal of inspiring as many students as possible cannot be reached without aggressively engaging the BEST Award. There is no desire for all students to be inspired towards engineering, science, and technology related careers. But our society's future will be shaped by the emphasis that our citizens (including this generation of students) place on these disciplines. In short, many of the students who do not choose engineering, science, and technology will become community leaders and national policy makers. We need to shape the priorities of our future leaders today. So, please make the most of the BEST Award opportunity.

Basic Criteria

Evaluation of competitors is generally based on the criteria outlined below. These are not the current guidelines and, in fact, there is generally some deviation between hubs. Since these guidelines are updated each year, it would be wise to refer to the most current rules that are distributed when the season starts.

In general, teams accumulate points (total possible 100 points) in the following categories:

Category I - Project Summary Notebook (mandatory for ALL teams, including teams NOT competing in the BEST Award)
Category II - Oral Presentation (at hub's discretion for BEST Award inclusion)
Category III - Table Display and Interviews (at hub's discretion for BEST Award inclusion)
Category IV - Spirit and Sportsmanship (mandatory for all BEST Award teams)
Category V - Robot Performance (mandatory for all BEST Award teams)

You local hub may omit either the Oral Presentation requirement or the Table Display, but not both.

Judging Procedure

A distinguished team of judges from private and public sectors with technical and non-technical expertise will evaluate teams. As each team completes a category, it will receive a category score that is the average of individual scores of the judges reviewing it. Teams should know in advance that scores among many teams frequently differ by only fractions of a point. Throughout the judging process, the judges may take into consideration the resources available to teams to conduct their BEST programs (financial or technology resources, for example).

Sample Guidelines (from 2004 season)

Category I: Project Summary Notebook

Guidelines

- The purpose of the notebook is to document the process the team used to design, build, and test their robot.
- ALL teams (whether officially competing for BEST Award or not) are required to submit a Project Summary Notebook.

- See local hub deadlines for more information on when the notebook should be turned in to the local hub.
- The notebook must meet the following specifications:
  - Submitted in a standard 3-ring binder with a maximum 2” ring size
  - 30 typed pages or less
  - Within the 30 pages, include a description of how the current year’s game theme is related to current technological practices or scientific research (minimum of 2 pages, maximum of 5 pages out of the 30 allotted).
  - Binder cover must identify the school, team name, and teacher contact.
  - Provide description of the process the team used to design and complete its robot.
  - Standard, 8 ½” x 11” paper, double-spaced, 1” margins, and Times New Roman (preferred) or similar business-style font no smaller than 12 pt. Single-spacing is acceptable in tables and outlines.
  - In supplemental appendices of up to 20 pages in length, teams may provide additional material as support documentation, such as drawings, photos, organization charts, minutes of team meetings, test results, etc. This material should directly support the process described in the primary document and NOT reflect activities related to community or promotional efforts, spirit development, or team-building.

Evaluation

- The notebook will be judged on the documentation of the team’s:
- Implementation of a formal engineering design process.
- Organized brainstorming approaches including organizing and documenting ideas.
- Analytical evaluation of design alternatives and use of mathematical skills in choosing design alternatives.
- Analysis of offensive and defensive strategies.
- Pursuit of design creativity to solve the problem presented in the game.
- Overall quality of notebook will also be considered
- Organization, appearance, adherence to specifications and quality of content
- Support documentation (e.g., CAD/other drawings, photos, organization, team minutes, test results, etc., that support the main document)

Category II: Oral Presentation

For the oral presentation, the team should view themselves as employees of a “company” that is marketing their “product” (robot) to a potential buyer (judges). This marketing team is an integral part of the engineering team that has designed a specialized robot. The marketing presentation should provide information about their company, the engineering team involved in the design and construction of the product, and why their product is the best one on the market that can complete the assigned task. The potential buyer will be assessing the following:

- The company’s design and manufacturing process (engineering process of “design to market,” including a discussion on the advantages of your company’s robot design)
- Discuss the technological resources your company used to design and construct the robot.
- Marketing strategies (e.g., school and community involvement, promotional efforts, etc.) to promote BEST
- Fundraising efforts and discussion of how funds were allocated
- The company’s demographics and operations (e.g., diversity of team members involved, team building experiences, displays of sportsmanship, etc.)

Guidelines

- A minimum of 4 students must actively participate in the presentation. A maximum of 8 representatives for the team may be in the presentation room, including the presenters.
- Adults are not allowed to participate, but may be present in the room (counting as one of the 8 representatives).

- Representation by student presenters from more than one grade level is encouraged and will be considered in the evaluation as part of the team's recruitment efforts.
- Videotaping/photographing by team representatives will be allowed during the presentation; however, the person(s) handling videotaping will be counted in the 8 maximum number allowed.
- The presentation format is the prerogative of the team.
- The team must provide any equipment it wishes to use, or check with the local hub for information about what equipment can be provided.
- The order and breakdown for the 25-minute presentation time period is as follows:

- 5 minutes: Set-up
- 12 minutes: Presentation
- 5 minutes: Q&A with judges
- 3 minutes: Break-down and clear room

Note: Teams not requiring set-up or break-down time may utilize that time for their presentation (for a total presentation time of up to 20 minutes).

Evaluation

Presentations will be evaluated with consideration of:

- Design and Manufacturing Process (Engineering Process) including brainstorming approaches, analytical evaluation of design alternatives, offensive and defensive evaluation, effective implementation of the process, and design creativity to solve the problem.
- Use of available technology.
- CAD or other drawings, web page development, computer simulations, etc.
- Marketing strategies.
- Efforts to promote BEST in school and community.
- Fundraising efforts/strategies and fund allocation.
- Company/team demographics and operations.
- Spirit/team building efforts, sportsmanship, diversity of team members, involvement with and mentoring to other schools/groups.
- Presentation's overall quality.
- Understandable, well organized, prepared, met specs., format, communication skills, presentation professionalism, Q & A quality.

Category III: Table Display and Interviews

The purpose of the table display and interviews category is to:

- Communicate through a display, and through discussion with judges, information about the team's efforts to promote BEST in the community and schools.
- Foster BEST spirit, camaraderie, and participation.
- Give evidence of sportsmanship.

Guidelines

- Each team will be provided with a standard six-foot long table (approximately 29 inches wide).
- Check with local hub for maximum allowed floor space for table displays (note: a 10' X 10' display space will be allocated per team at the regional competitions).
- Skirting for the table will not be provided.
- Each team should bring one extension cord and one power strip.
- Other display items may be used but must not exceed the space allocated by the hub.
- Teams are encouraged to avoid using expensive store-bought display boards and structures and opt for more creative and hand-made display props.
- Any audio-visual equipment needs and extra extension cords will be the responsibility of the team.
- Each team is responsible for security of its own material.
- Each team is also responsible for breakdown of its team materials and clean-up of its display area following the awards ceremony on Game Day.

- All material should be clearly marked with the appropriate identification and contact information.
- Check with the local hub concerning when and where table displays can be set up.
- Candy and other food items are not permitted at table exhibits as complimentary handouts.
- During the designated interview time, at least one student representative from the team must be present who is able to respond to informal questions asked about the display. These questions will be part of the interview evaluation of the team.
- Teams should expect to be visited by three different judges during this period.
- Judges may also interview team members in the pit area and in the seating area.

Evaluation

- Displays (15 points) will be evaluated on:
- Promotion of BEST, including recruitment and information-sharing with other schools, presentations, and demonstrations.
- Use of technology, display models or boards, or multimedia in promotion of BEST.
- Creativity in design and presentation of display.
- Publicity activities (publicity materials, media/press, fund raising efforts in school, and community efforts to other schools and community groups).
- Compliance with above guidelines.
- Interviews (10 points) will be evaluated on:
- Enthusiasm and learning experience from BEST.
- Team recruiting (cross section of student population with multigrade levels).
- Level of student participation (students were the primary designers and builders of the team's robot).

Category IV: Spirit and Sportsmanship (15 Points)

- Judges will evaluate this category on Game Day.
- They will observe the spirit promoted by the team during the competition rounds as well as the team's conduct throughout the day in the seating area, table display area, game floor, and pit area.

Evaluation

- Spirit includes the vigor, enthusiasm, and animation displayed by team representatives.
- Teams can use posters, cheerleaders, musicians, mascots, and costumes to increase the level of spirit.
- Sportsmanship includes outward displays of sportsmanship, grace in winning and losing, and conduct and attitude considered befitting participation in sports.
- Overall team sportsmanship is also demonstrated by students (not mentors) making the majority of robot adjustments and repairs during the competition.

Category V: Robot Performance (5 Points)

- The fifth category, Robot Performance, will determine the final 5% of possible BEST Award points. These 5 points will be based on the total game points earned throughout the seeding competition (prior to the championship rounds) according to the following scale:
- Team finishes in top 20% of all teams competing at hub	5 Points
- Team finishes in top 40% of all teams competing at hub	4 Points
- Team finishes in top 60% of all teams competing at hub	3 Points
- Team finishes in top 80% of all teams competing at hub	2 Points
- Team finishes in top 100% of all teams competing at hub	1 Point
- Team is unable to score any points during the competition	0 Points

Categorical Tips

As with any subjective evaluation, there will be considerable variability in the values and evaluations of individual judges. The judges are given the general guidelines and score sheets, but it is up to them to interpret the intent and set a standard. Consequently, originality can yield great influence as a team grasps for the judges' attention. But be careful that your creative ploys do not distract from the content that you are presenting. It would behoove you to reference past judge score sheets (in the Example Documents section) when preparing materials for submission.

Notebook

It is essential that the team learns and follows a disciplined step-by-step design approach and practices good documentation at every step. If this is the case, then a good notebook is easy to compile. Some general things to keep in mind:

- Imagine you were trying to audit an outside contractor to verify that they considered all aspects of the problem, considered all possible alternatives, and employed the best available resources to solve the problem. What documentation (and what quality documentation) would you want?
- There are very distinct phases of the design process. They should be very influential in creating the outline for your notebook (but don't be too obvious about it).
- Documentation at every step should be thorough enough to be referenced by an unrelated party at a later date. This does not mean hours in front of a CAD station every day. It does mean that even rough sketches should be named and labeled to help the reader interpret the sketch. Include in the notebook only enough of the rejected design alternatives to prove that you were thorough. Too many can simply be distracting.
- Decisions should never be made by popular vote. Subject design alternatives to a mathematical decision matrix. You'll be surprised how this will yield unexpected choices while helping the team to integrate the better attributes of various alternatives into a single comprehensive solution.
- An engineering challenge is rarely as simple as it appears at first glance. Thoroughly analyze the problem and break the design down into constituent functions. At each level of detail, a matrix of requirements should be documented dividing the requirements into various categories (i.e., operational rules of engagement, robot requirements, wishes versus demands, etc.).
- Don't forget to plan a detailed schedule (with design/build milestones) and document the challenges that the team encountered while trying to reach those milestones. (Gantt charts can look pretty good in formal reports.)
- Don't forget to include testing and refinement in your process. Even if you haven't completed this phase of the design process when your notebook is due, you can still document a detailed test plan. Official testing of the components should be documented as parts are produced. The performance requirements should have been part of the problem definition for each part.
- Team organizational structure should be included, but don't include so much detail that it becomes a distraction.
- The notebook is NOT the place for community involvement, promotional efforts, spirit, or team building efforts. Please do not submit a photo scrapbook. It should be a technical document (obviously written by kids).

Oral Presentation

The judges on the local level don't expect a perfect presentation. They do expect that the presenters personally understand the program and the experience that the team had. A flawless presentation followed by shallow responses during the Q&A portion would not be as effective as a team that has a fluent presentation and can improvise well if some glitch occurs with the technology during the presentation. The presenters should be well rehearsed, but they should not be automatons. Presenters should be clearly interacting with the slides but not dependent on them for details.

Students need to provide information to the judges concerning the teams experience in the BEST program and the team's final product including:

- The team organizational structure and pursuit of diversity.
- The basic design process that was employed.
- Care taken at each step to ensure quality of the final product (includes use of available technology and team building efforts).
- The final robot design.
- Advantages of the chosen design over alternatives.

- Recognize disadvantages and acknowledge intentional tradeoffs.
- The build/test/refinement process.
- Adopted schedule and project budget.
- Promotional effort aimed at school and community.
- Examples of sportsmanship.
- Understanding of some lessons learned in the process.

Table Displays and Interviews

The Table Displays category is probably the least defined and creativity can really shine. There are two mistakes to avoid. First, don't think of the Table Display as a table…think of it more like a 3-D interactive booth to convey information and enthusiasm simultaneously. Second, don't focus so much on creative expression that the observer loses focus of the significant content. Content that you might want to integrate into your Table Display includes:

- Efforts to recruit future teams/participants and information sharing with other existing teams.
- Recruitment and representation of students for the school's BEST team.
- Publicity efforts and fund raising activities.
- Presentations and demonstrations you've done.
- Use of technology in designing and marketing the robot.
- Photo record of your design process.
- Failed prototypes or story of how you overcame challenges.
- Technical justification for your team theme.
- Level of student participation (number and diversity of students and their roles).
- History of your school's participation.

Things that the judges might be looking for when they visit your Table Display:

- Compliance with published table display constraints
- Student's enthusiasm
- Evidence that ALL the team members learned something about engineering, not just the design subteam and the build subteam.
- Understanding of some lessons learned in the process
- Creativity in the table display
- Use of technology in the display

Spirit and Sportsmanship

This category is a two pronged assessment of how well the team addressed the implied underpinning of the BEST competition. First, if the team is really getting the word out that engineering, science, and technology are important, then there should be a lot of nonteam members in the stands supporting the team. Second, each participant needs to recognize that we are all part of a team trying to increase technology awareness and appreciation across our communities. As teams are trying to "beat the competition," they must constantly be mindful that the real goal is to inspire them. Though spirit is something that can be faked during the last minute preparation for game day, sportsmanship is something that the coach will have to diligently pursue from the very first team meeting.

Final Tips and Wisdom from Experienced Coaches

- A well thought out plan will save a lot of headaches, but flexibility is paramount because there are many factors beyond your control.
- Focus on the process not the end product. This way the students will learn important lessons even if they can't pull things together by game day.
- Every team member is capable of making a unique contribution.
- Keeping the team on schedule is the coach's biggest challenge. Don't let the team engage "unreasonable" goals until they have the basic goals solidly achieved.
- Form a parent booster club to manage how parents can be involved even in small ways. Delegate as much responsibility to the parents as is possible (e.g., snack coordinator, non-kit material coordinator, fund-raising monitor, game-day lunch coordinator, etc.)
- Don't do it all yourself - DELEGATE!
- The students will get the most from the process if they do the work.
- Use the Socratic method (pose detailed/leading questions) to help the team think through ideas completely…don't just show them by example or tell them your preferred solution.
- Students don't naturally know any formal problem solving process. Someone will have to formally present one to the team. It won't hurt to post it on the wall.
- Implement a "wall of progress." Choose a long empty wall and post the steps in your project life cycle along the wall. Throughout the competition post anything and everything that is "produced" (for robot documentation or BEST Award efforts). This includes outlines, sketches, drawings, and lists of ideas. Anything that has even a small chance of being integrated into the notebook or BEST Table Display should eventually be redone and posted in "final form." The wall will then serve as a storyboard of the team's process. (Make copies and protect the wall as if it were a valued treasure map.)
- Students working without adult presence make few quality decisions.
- Very limited progress can be made on the robot without mentors present.
- A chassis on the ground is worth two on the chalkboard and 10 on CAD!
- If everyone is responsible for charging the batteries, the batteries will be dead.
- With time and patience, you can bend PVC pipe with the steam from a teakettle.
- The team will adopt the spirit and sportsmanship of actively involved mentors.

Example Documents

Student Recruiting Poster (ppt) Examples BEST Table Displays (doc)		Provided by Greg Young of Capitol BEST
3-min Student Recruiting Video (wmv) 3-min Teacher Recruiting Video (wmv)	Play it in the cafeteria, over the school video system, etc… Slightly different twist aimed at teachers.	Created by Dr. Michael Wienen for BEST Robotics Inc.
Judges score sheets (doc)	Example score sheets used by BEST Judges	Created by Mary Lou Ewald for BEST Robotics Inc.
Team Member Contract (doc) Parent Information Sheet (doc) Common Sense Guidelines (doc)		Provided by San Antonio BEST volunteers
Example photo release statement (doc)	Coaches can modify it to permit the school and the team to use the photos.	
General permission to participate Safety Contract and Permission Form "How to Win the BEST Award" (doc)	Should include event dates, general meeting requirements, and coach contact information	Provided by Leah Martaindale of Coastal Bend BEST
Sample Tool Safety Assessment (doc)	This is not a comprehensive assessment. It can only generally represent the students' understanding of tool safety.	
Example Student Presentation Team/Club Charter (pdf) Another Example Team Charter (doc) Team Notebook (pdf) Another Team Notebook (pdf)	**These student productions are for evaluation purposes only. Information may not be re-used without permission from original authors.**	

Learning Resources:

Kansas BEST Video (wmv)	15 minute informational video (high quality version can be downloaded from "start a new hub" link at www.bestinc.org)	Provided by Kansas BEST
Teaming – Mars Pathfinder Case Study (doc)	Possible reading assignment for your team before kickoff	Provided by Alabama BEST
Teaming – Team-building activities (doc)	Simple activities for your team to warm up on before kickoff	Provided by Dr. George Blanks of Alabama BEST
Soldering Tips (html) Debugging a Robot (html)	Includes basic schematics and diagrams to get the electronics wired up and the wheels attached	Provided by Mike Blazer of San Antonio BEST
Kit Introduction (pdf)	Introduction only. Please refer to detailed Hub information.	Provided by San Antonio BEST volunteers
Dizzy (html) Robot Gallery (zip)	Example robots. Your team might gain some insight into various mechanisms that are possible. **However, viewing these might stunt their imagination.**	Provided by Dr. Michael Wienen of Brazos BEST
Navy Dimensioning (pdf) Industry Drawing Guidelines (pdf)		Provided by Dr. Richard Link of the US Naval Academy Provided by Quartic Engineering Ltd.
Basic Mechanical Analysis (pdf)		Provided by Chris Cormier of Collin County BEST