

Maker Resources:

Computer Aided Design and Digital Fabrication

Presented by the Charles Z. Guan Center for Kids Who Can't Robot Good
and Wanna Learn to Build Other Stuff Good Too



Everyone builds something like *this* at least once...



Maker Resources

A primer on modern resources available to the mechanical hobbyist, with emphasis on making better devices through computer-aided design and engineering and accessible digital fabrication resources.

- **Design it**

- Why design before you build it?
- Computer Aided Design software

- **Fab it**

- Using your CAD output for 3D printing, abrasive waterjet and laser cutting
- Making the 3D from the 2D and machine design techniques

- **Source it**

- Materials, motors and actuators, battery and power, sensing and control

- **Read it**

- Build blogs, Instructables, index sites

About Me

- Engineering hobbyist since 2001
- Dragon*Con attendee since 2002, competed in Robot Battles since 2003
- Mobile projects (robots, electric vehicles) with mechanical, electronic, and software integration
- MIT Mechanical Engineering S.B. (kind of like a B.S.) 2011, S.M. 20_{someday}
- Fabrication / shop instructor, electric vehicle design lab course at MIT
- Generally like that people build things for fun and self-betterment.



Design it: Mechanical Design Software

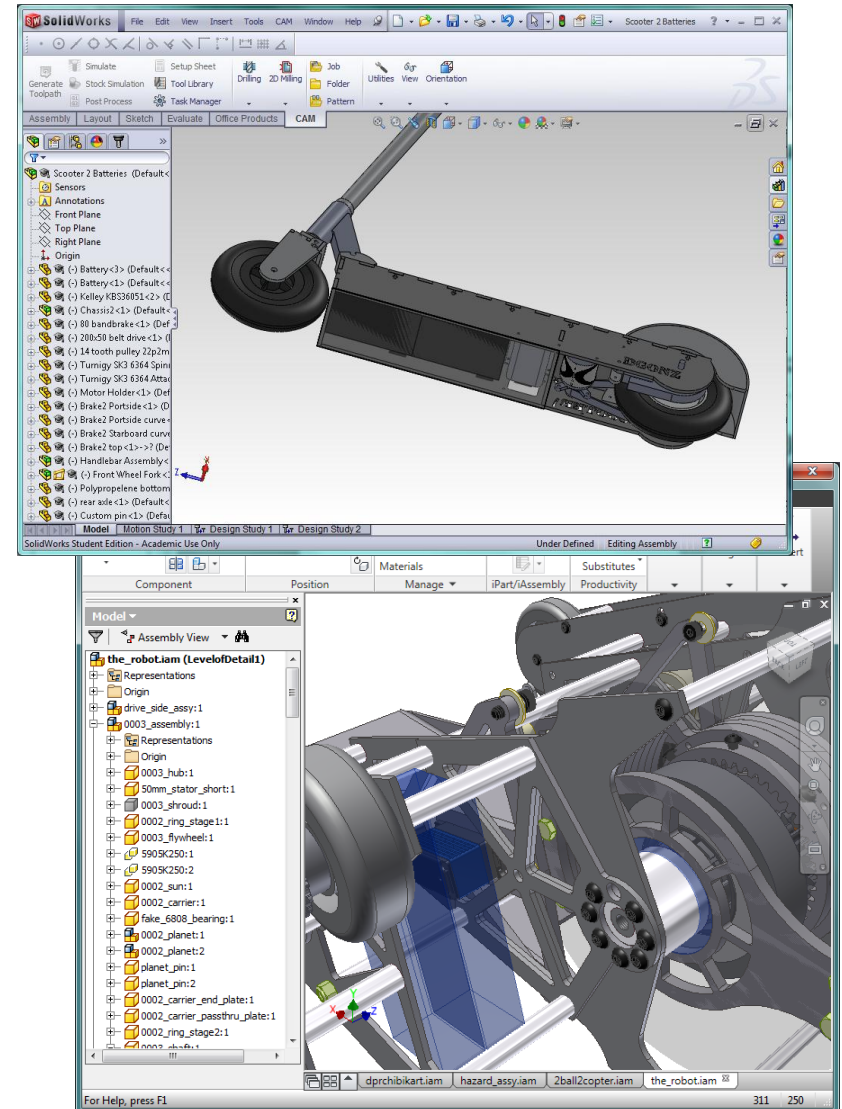
- 3D Computer Aided Design tools let you design parts and virtually assemble & analyze them to validate the design before fabricating.

- **Free:**

- Sketchup (now no longer Google) Pro & Make
 - Make version cannot export most files
- Autodesk 123D Design & Make
- freeCAD – under development

- **Not So Free:**

- Solidworks (student license) \$150
- Autodesk Inventor (student license)
 - Free 3yr with .edu or other affiliation
- Rhinoceros (25-save trial)
- ViaCAD (\$100 – 250)



Why CAD?

- **Beginner**

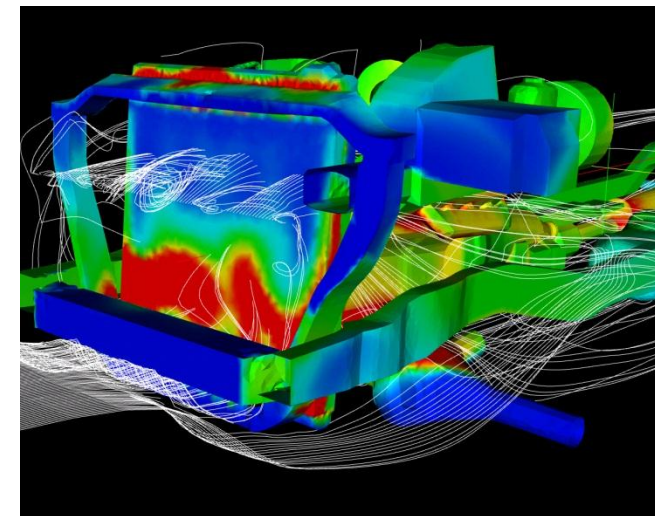
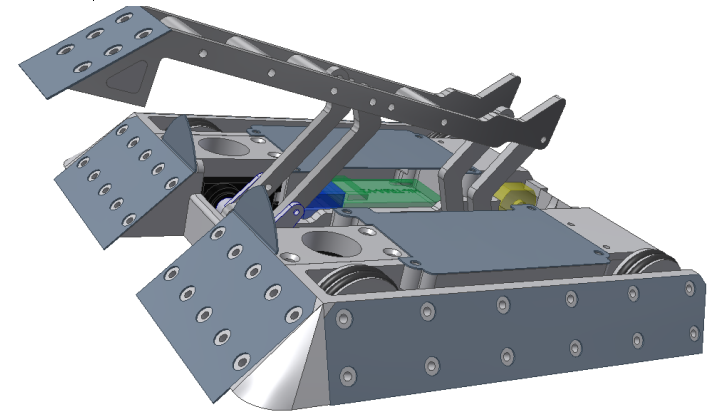
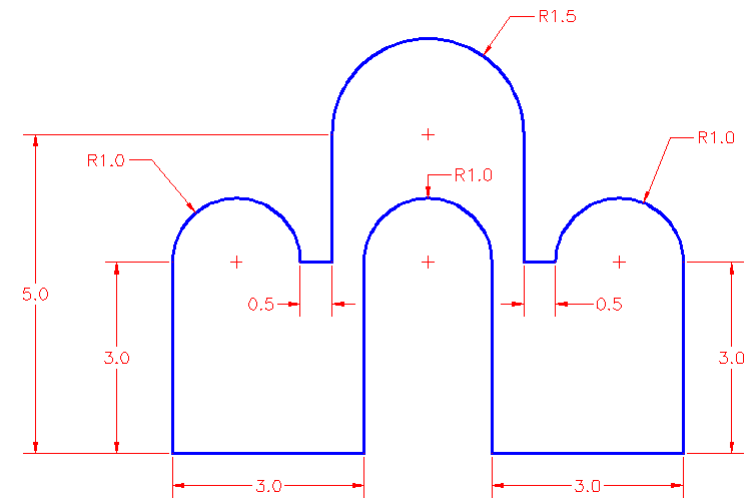
- Draw shapes, sketch your ideas, make templates to cut out parts manually

- **Intermediate**

- Create 3D mechanical parts, mate and simulate motion, export digital fab files, technical drawings

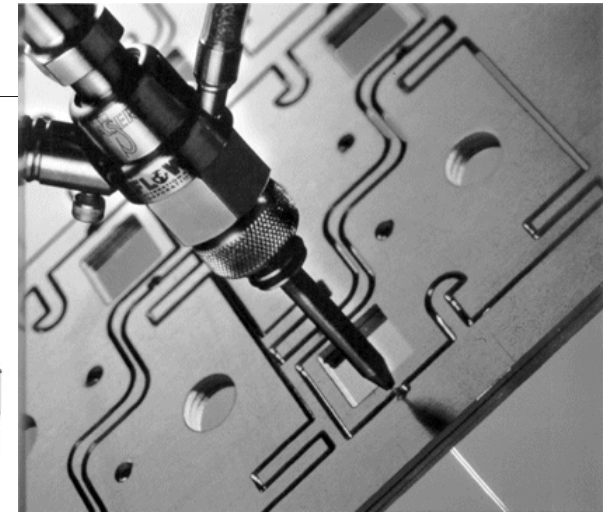
- **Advanced**

- Fully integrated 3D models including wiring harnesses, fluidic systems. Flow simulation, injection molding simulations.
- “Computer Aided Engineering”



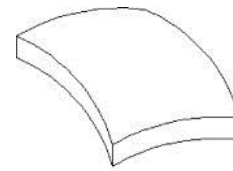
Fab It: Rapid Prototyping and Digital Fabrication

- Waterjetting, 3D printing, and laser cutting are computerized processes which now have easy online instant quoting
- **Laser Machining:** Giant laser lights your material on fire very scientifically
 - Some materials can't be laser cut due to toxicity or heat damage
- **Abrasive Waterjet Machining:** Very powerful water gun shooting into a sandblaster at 60,000+ PSI. Will cut most materials known to mankind.
 - Cut hardened steels, ceramics, and stone as easily as wood
- Technologies commonly referred to as “digital rapid prototyping”
 - Or just “rapid prototyping”

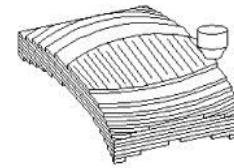


Fab It: ~~Defense Against the Dark Arts~~ 3D Printing

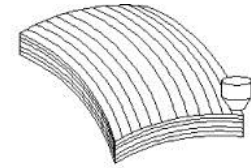
- 3D Printing: Stacking layers of 2D prints to make a 3D project. Common techs:
- **FDM / FFF** Lays down *noodle* of plastic
 - Mature technology, hobby-grade equipment available
 - RepRap, Makerbot, et al.
- **SLA / Stereolithography** Cures a *goo* via focused laser or scanned UV image
 - Maturing technology
 - Some hobby-class, e.g. Form 1
- **SLS / Selective Laser Sintering**. Melts *powder* together with large laser
 - Still commercial and expensive
 - North of \$250,000+



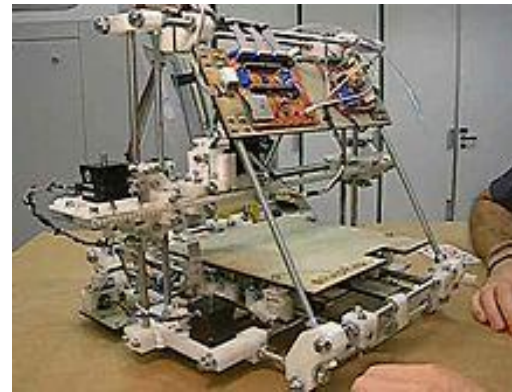
(a) A curved model



(b) flat layers

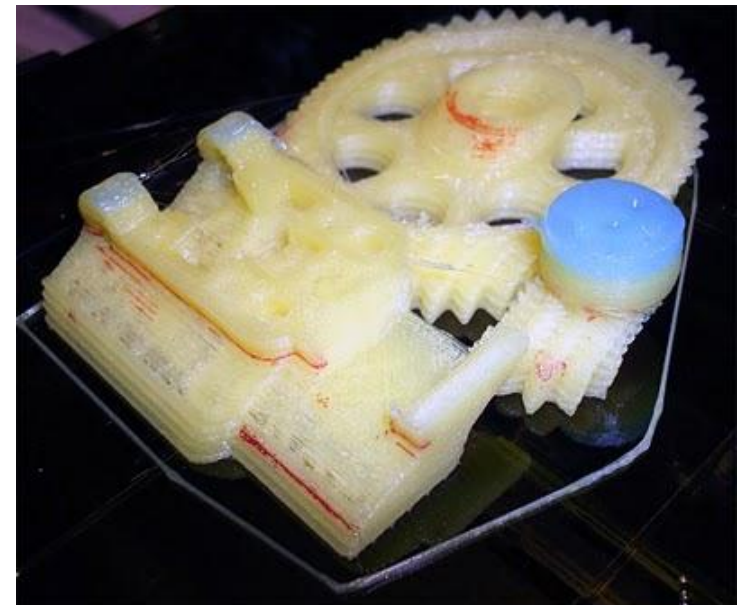
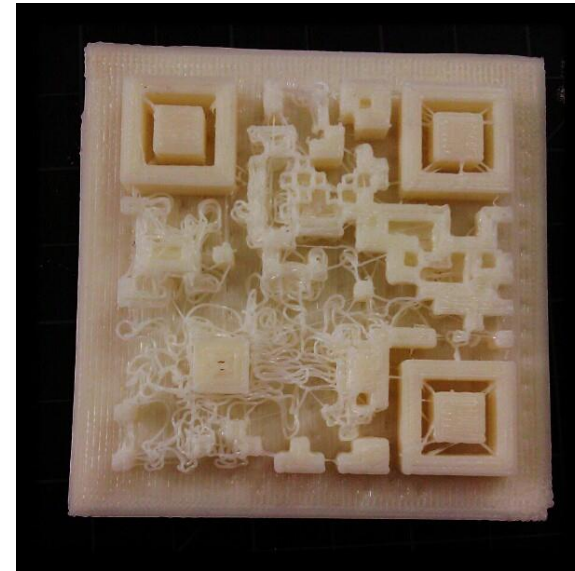


(c) Curved layers



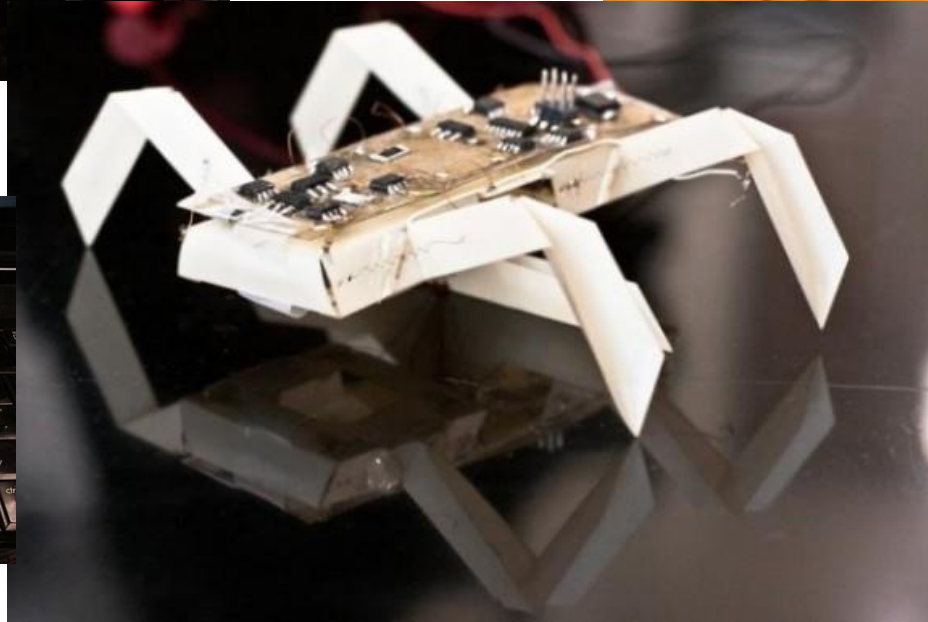
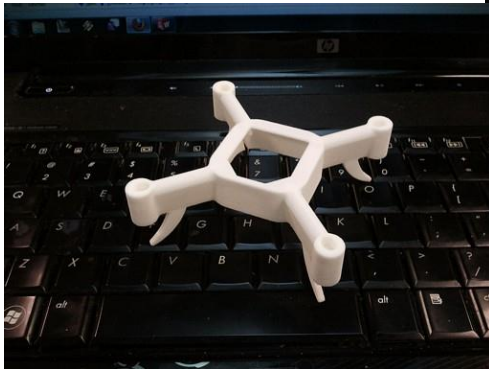
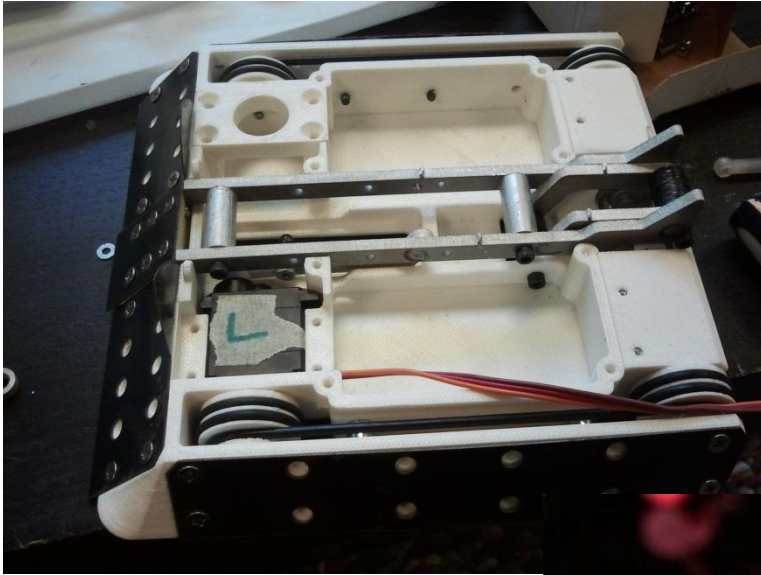
Fab It: ~~Defense Against the Dark Arts~~ 3D Printing

- 3D printing must be used cautiously!
 - Materials are often not structural
 - **SLS FDM SLA**
- **Too easy to make an impossible part!**
 - Convenient, but encourages poor design practice
 - Limited resolutions and minimum cross sections (especially FDM)
- Used extensively in industry for prototyping and looks-like (not works-like) models
- **Ill-suited for production**
 - Time and expense are linearly scaled since parts are generally made one by one
- tl;dr 3D printing will not save the universe; mechanical aptitude needs to be used concurrently with the technology.



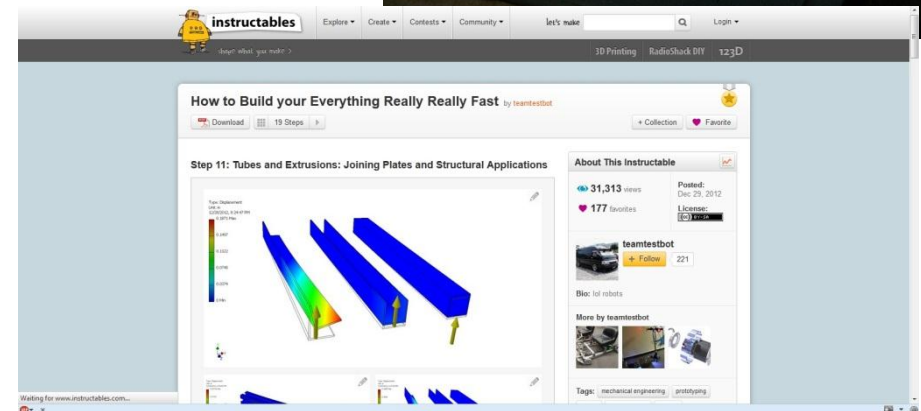
Fab It: ~~Defense Against the Dark Arts~~ 3D Printing

- Doesn't mean it's *all* bad...



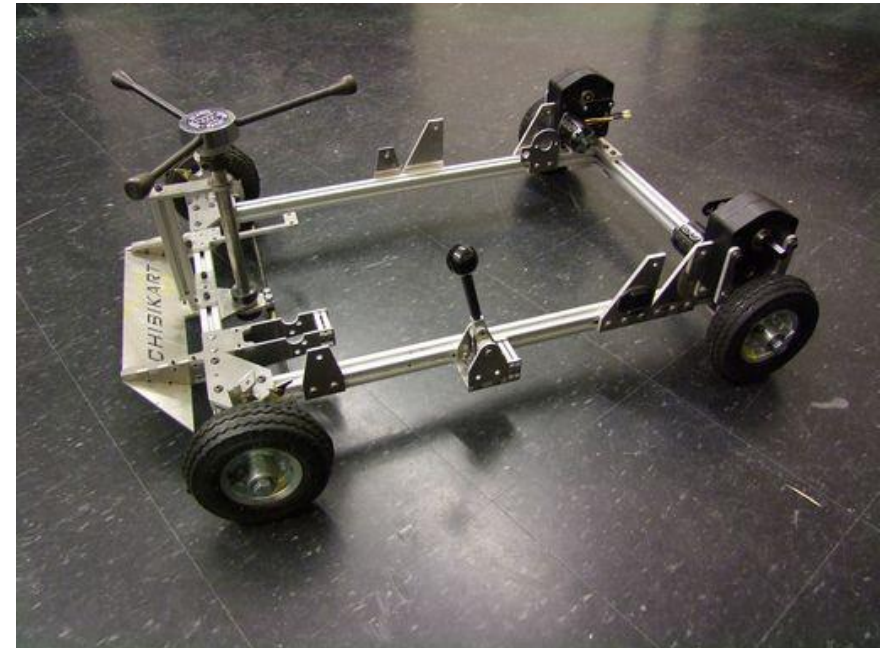
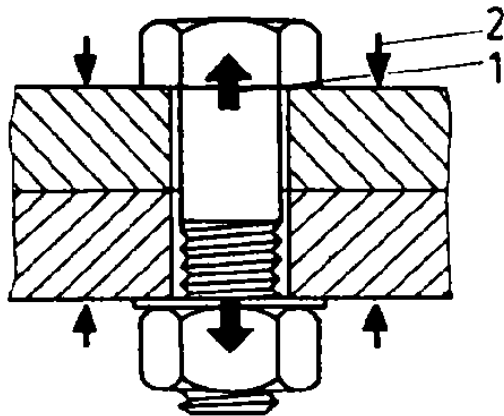
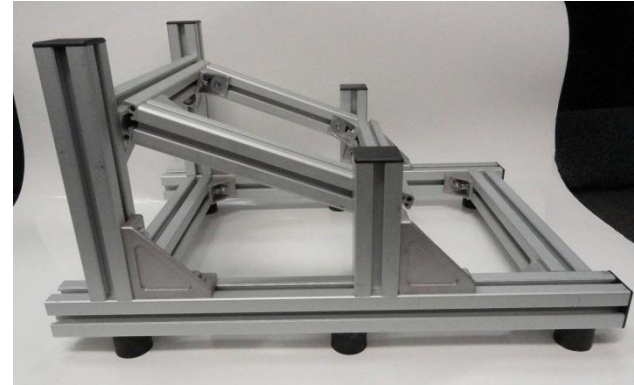
Fab It: Making 3D from 2D

- Availability of 2D processes plus some creativity on your end = robust 3D machinery without touching a single machine tool
- Adaptation of woodworking techniques *and* sheetmetal working techniques
 - Gussets, trusses
 - I-beam, web-and-flange
 - Making boxes and cases
 - Mortise and tenon joints (“slot and tab”
 - “T-nut, Pettis Joint, etc.” fastening
- **How to Build Your Everything Really Really Fast:** Written for MIT Mech. E. students, generally useful
 - Basic machine design overview
 - **TIGHTEN YOUR SCREWS OR ELSE**



Fab It: Making 3D from 2D

- Using stock & purchasable industrial components with 2D plate design means more structures are possible
- 80/20 T-slot extrusion
 - Many accessories available
- Spaces, standoffs, threaded rods
 - “Preloading” the structure for more rigidity
- 3D printable “corner joists” and “angle blocks”
- **TIGHTEN YOUR SCREWS OR ELSE**



Electronics CAD

- **Eagle**

- Free version lets you design up to 4 x 3" boards, 2 layers
- Worst user interface ever, but a standard for years

- **DipTrace**

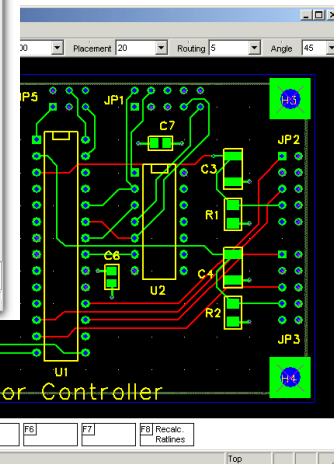
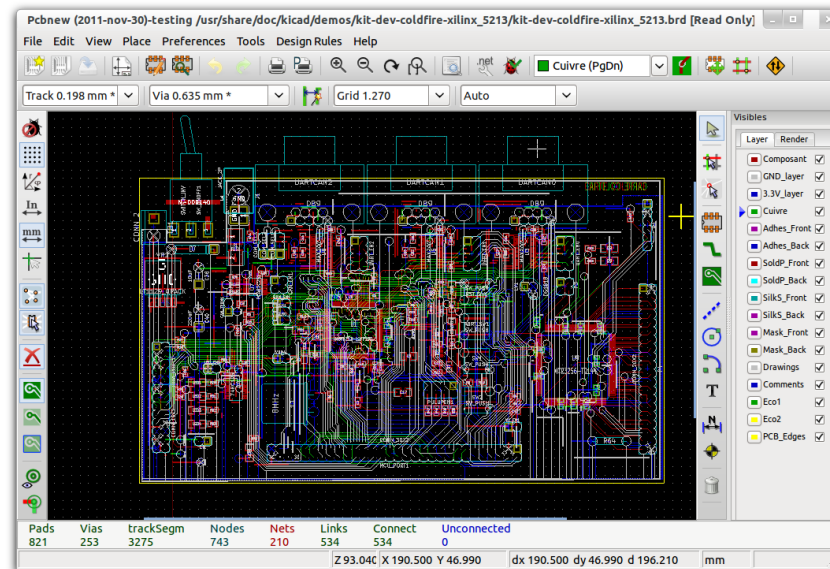
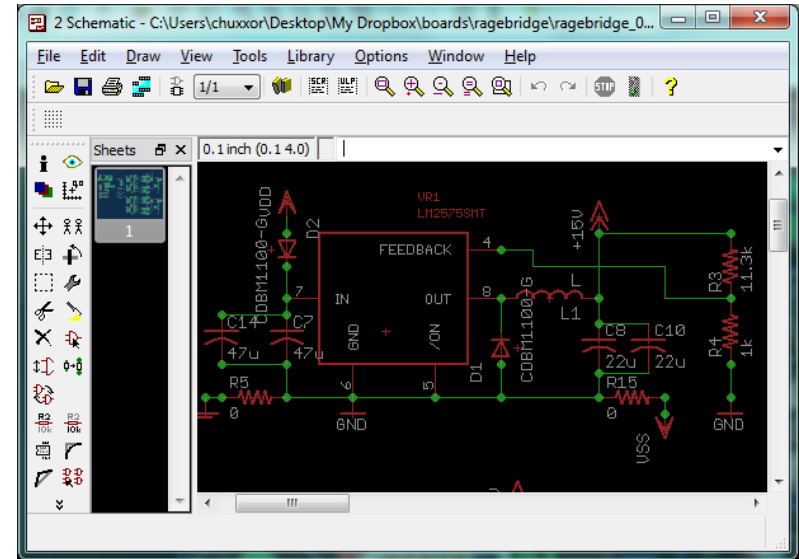
- Nice "professional" software, has hobbyist edition like Eagle

- **KiCAD** (Nice full-featured OS)

- **FreePCB** (OS)

- Vendor-specific

- (ExpressPCB, PCBArtist...)
- Fabrication services
- No schematic design, just layout



Helpful Online Resources

- Torque and Amp-hour calculator
 - architeuthis-dux.org/torquecalc.asp
 - Simulation of robot drive trains – acceleration, current draw, battery life
 - Geared toward combat robots, but can be pressed into service for most motor-driven things
- Falstad Circuit Simulator
 - falstad.com/circuit
 - Easy to use electronic circuit simulator (think SPICE software)
 - Most types of components available
 - Geared towards logic & analog circuits

Torque / Amp-Hour Calculator

Motor: Torque Constant:
oz-in/amp

Stall Amperage: Voltage Constant:
RPM/volt

Operating Voltage:
volts

Weight Class: Robot Weight:
lbs.

Motors per Side:

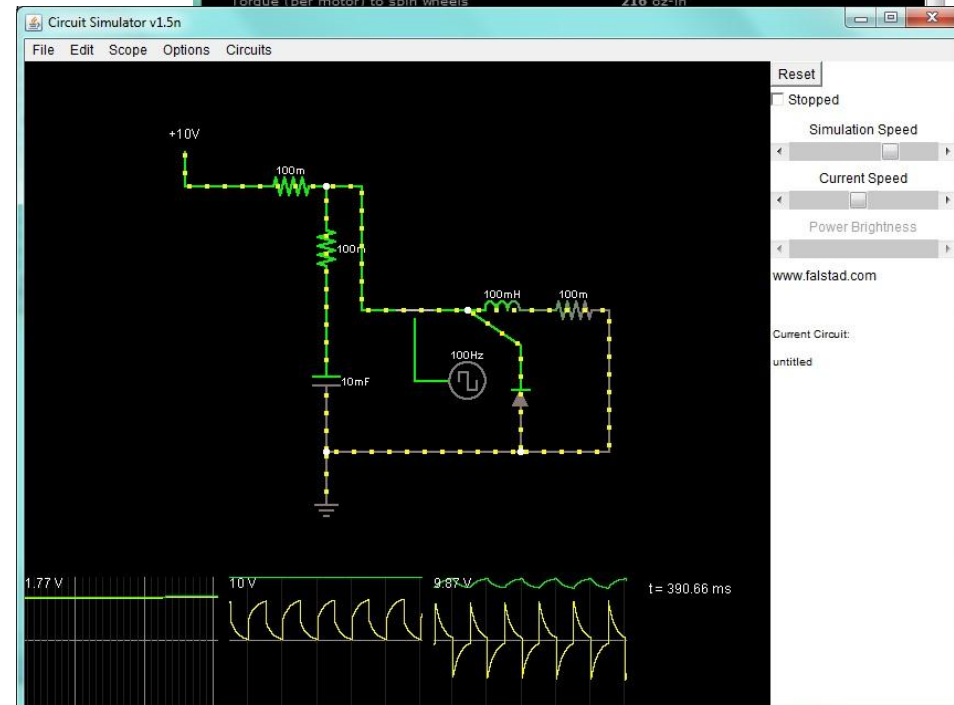
Wheel Diameter: inches Tire Coefficient of Friction:

Gear Ratio: : 1

Average % of Peak Drain: e.g. what % of peak is the average?

High Contrast Version:

Torque (per motor) to spin wheels: 216 oz-in



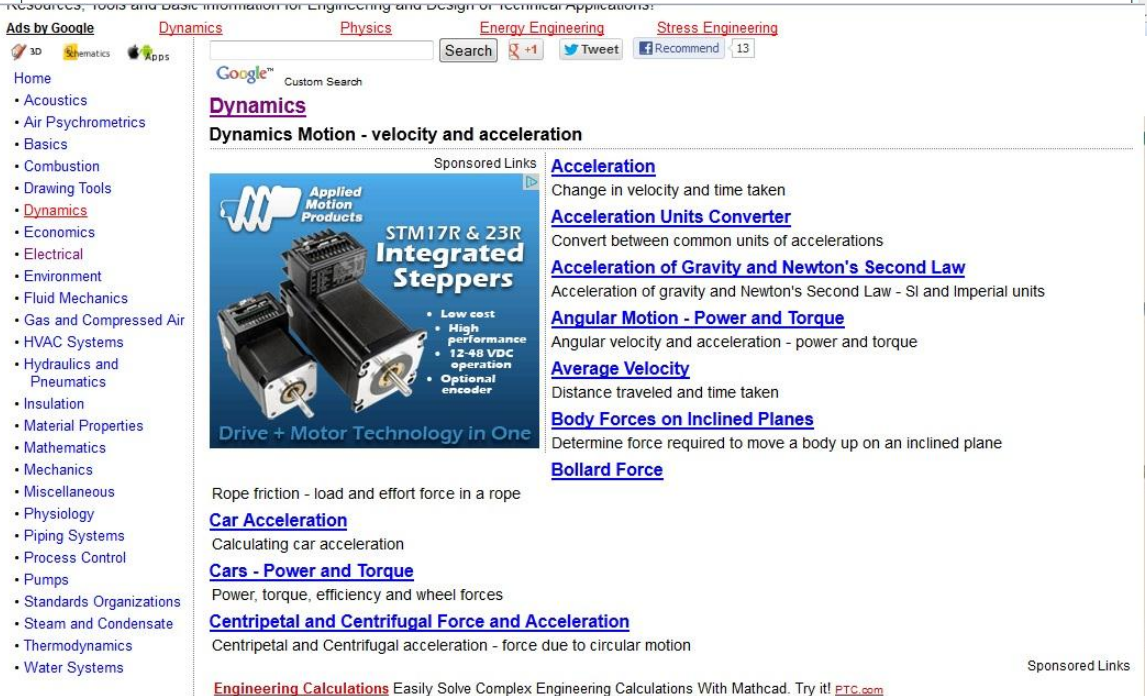
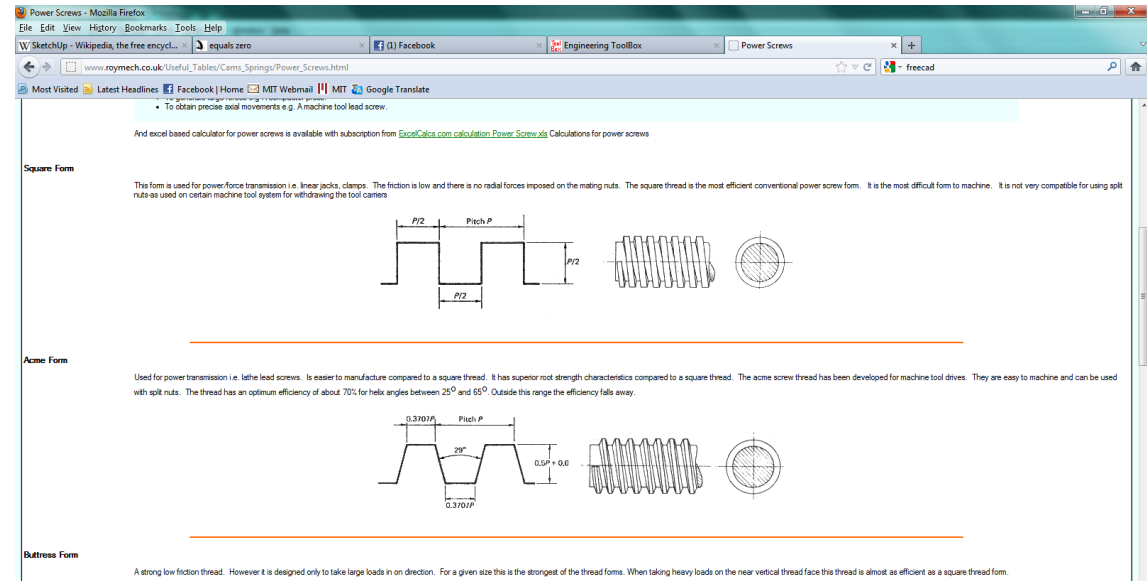
Helpful Online Resources

- **Roymech.co.uk**

- Excellent resource for learning about mechanical parts (gears, belts, shafts, chains, screws) and machining processes

- **Engineeringtoolbox.com**

- Online engineering repositories
- Calculators for bearing loads, wire gauges, drills and tap charts, ec.



Read it: Resources for Learning

- Reading and looking at other peoples' builds is one of the best ways to discover new methods and resources!
- **Builders' blogs:**
 - etotheipiplusone.net – Charles' site. Sidebar links to *many* more sites.
- **Hacking/Modding websites:**
 - hackaday.com, hackedgadgets.com, blog.makezine.com, Adafruit Blog
 - Generally link to builders' sites if they are available
- **Books**
 - *Making Things Move: DIY Mechanisms...* Dustyn Roberts
- **Make Magazine and Maker Faires**
 - Atlanta Mini Maker Faire at Georgia Tech, Oct. 26 (<http://makerfaireatl.com/>)
- **Instructables.com**
 - Step-by-steps, guides, instructional videos.

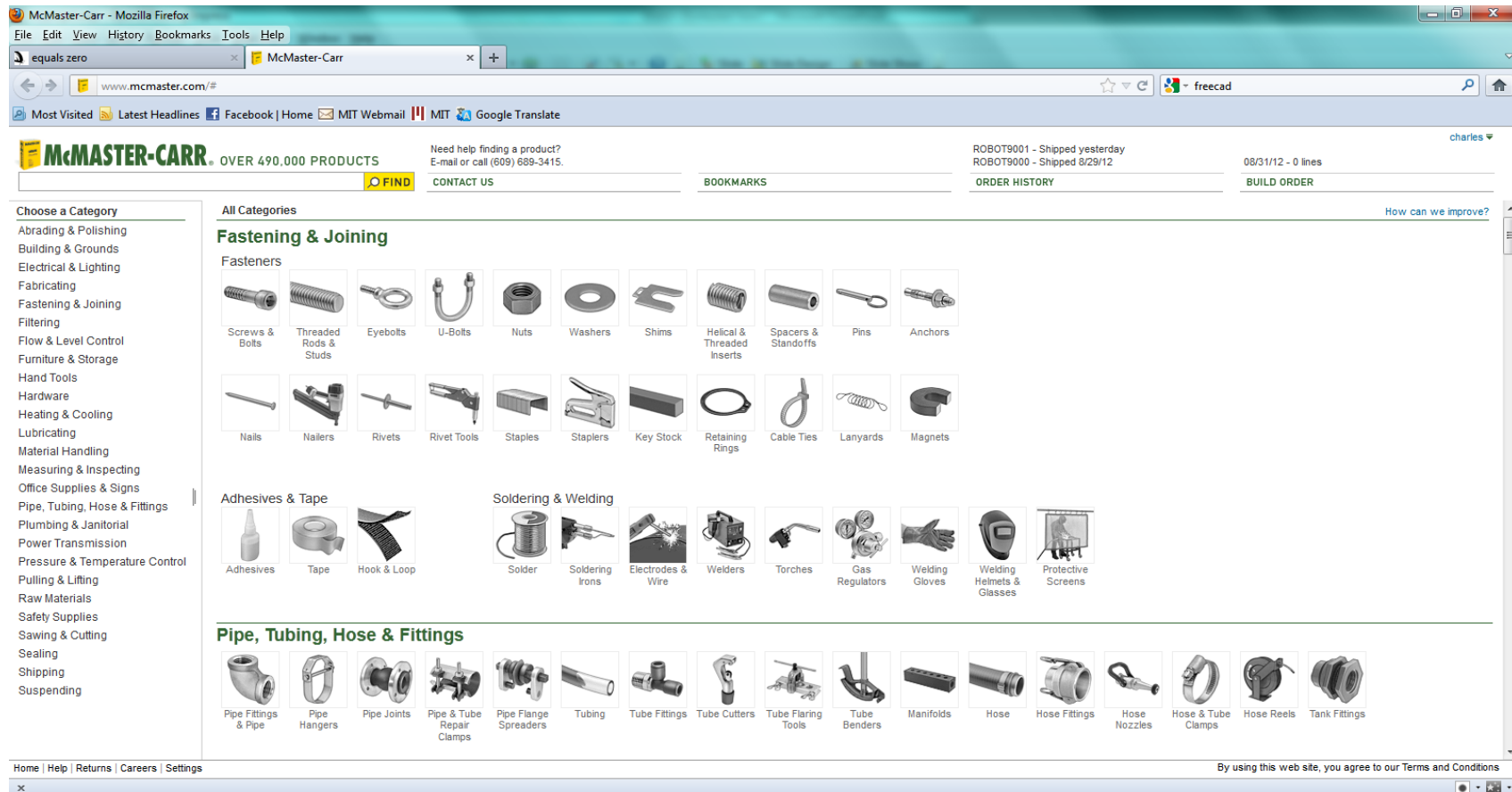
Major Lessons

- CAD allows you to plan ahead, see how things will fit and move.
- More resources than ever are available to the non-machine-endowed public with just a little bit of computer skills
- Digital fabrication resources turn a virtual model into real parts with little manual intervention or steep machine operation learning curve (and access)
- To make the most of these resources, becoming familiar with some aspects of mechanical engineering and design is helpful.
- The Internet is full of things which you can buy.

Q&A and Discussion
CAD program demonstrations
Resources and Purchasing

Source it: Beyond Home Depot

- McMaster-Carr Supply (mcmaster.com)
- Pretty much the end-all, be-all of mechanical parts and tools. Downloadable CAD models for most fasteners, power transmission products.
- Link-rich website, easy navigation and searching by specification



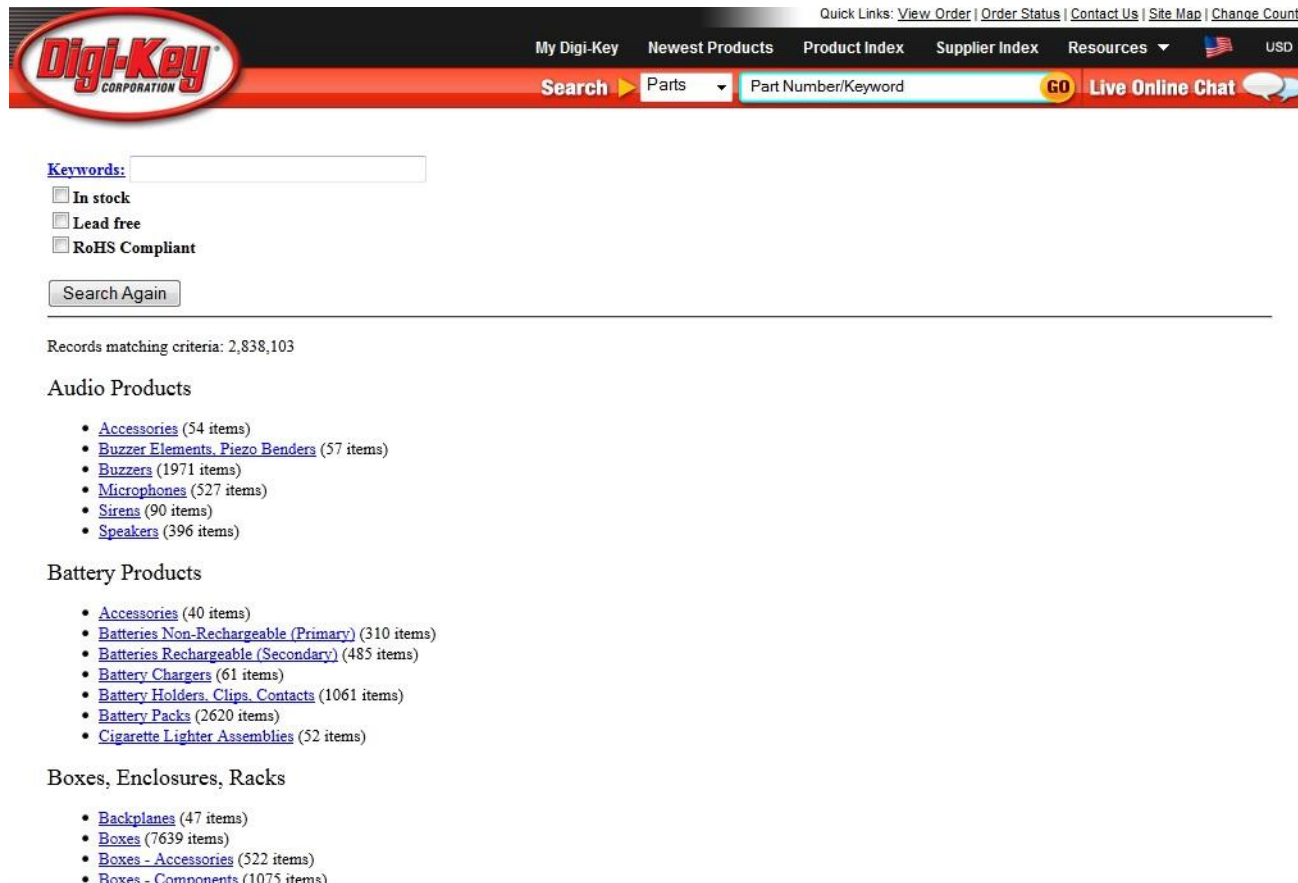
Source it: Materials and Mechanical Parts

- Other industrial suppliers
 - MSC (mscdirect.com)
 - Tools and machinery
 - Grainger (grainger.com)
 - HVAC and industrial process control, contractor supplies
 - Fastenal (fastenal.com)
 - Hardware, tools, bits and cutters, joining
- Worse websites, customer service

The screenshot displays the MSC Industrial Supply Co. website interface. At the top, there is a search bar with the text "Keyword, MSC, Mfr, Competitor, Customer part #..." and a "GO" button. To the right of the search bar, there are links for "Login", "help", and "register", along with fields for "username:" and "password:" and a "GO" button. Below the search bar, there is a navigation menu with links for "HOME", "ORDER", "SPECIAL OFFERS", "RESOURCES", "SOLUTIONS", "ABOUT MSC", "CUSTOMER SUPPORT", and "MY ACCOUNT". The main content area is titled "Product Categories" and lists various categories such as "Abrasives", "Clamping, Workholding & Positioning", "Fasteners & Adhesives", "Fleet Maintenance", "HVAC", "Hand Tools", "Hardware", "Holemaking", "Hose, Tube, Fittings & Valves", "Indexable Cutting Tools", "Janitorial & Facility Maintenance", "Lighting & Electrical", "Lubricants, Coolants & Fluids", "Machinery", "Marking & Labeling", "Material Handling & Storage", "Measuring & Inspecting", and "Milling". The "Fasteners & Adhesives" category is expanded, showing a grid of product images and descriptions: "Adhesives, Tape & Hook & Loop", "Anchors", "Bolts & Screws", "Fastener Sets", "Fasteners For Electronics", "Grommets & Grommet Installation Tools", "Nails & Staples", "Nuts, Washers & O-Rings", "Pins, Clips & Retaining Rings", "Rivets, Threaded Inserts & Tools", "Screw, Bolt, Stud & Pipe Extractors & Nut Splitters", and "Threaded Rods, Threaded Studs & Mounting Flanges". On the right side of the page, there is a "Quick Order Pad" with a table for "Part #", "Type", "Part #", and "Qty". Below the table are buttons for "ADD TO CART", "CLEAR", and "MORE ROWS". There are also "Promotions" and "Special Offers" sections on the right, including a "30% OFF Drills & Taps" promotion and a "25% OFF Hose, Pneumatics & Fluid Power" promotion.

Source it: Materials and Mechanical Parts

- **DigiKey** One of the largest electronic component suppliers, for DIY circuits and boards. Search by specifications. Although not **the** largest, it is very popular with hobbyists due to its relatively easy to use website.
- **findchips.com** and **octopart.com** For cross-vendor searching of a specific part.



The screenshot shows the Digi-Key website interface. At the top, there is a navigation bar with the Digi-Key logo on the left and quick links (View Order, Order Status, Contact Us, Site Map, Change Country) on the right. Below the navigation bar is a search bar with a dropdown menu set to 'Parts' and a search input field containing 'Part Number/Keyword'. A 'GO' button and a 'Live Online Chat' button are also visible. Below the search bar, there is a 'Keywords:' input field and three checkboxes: 'In stock', 'Lead free', and 'RoHS Compliant'. A 'Search Again' button is located below the checkboxes. The search results section shows 'Records matching criteria: 2,838,103'. The results are categorized into three sections: 'Audio Products', 'Battery Products', and 'Boxes, Enclosures, Racks'. Each section contains a list of product categories with the number of items in parentheses.

Quick Links: [View Order](#) | [Order Status](#) | [Contact Us](#) | [Site Map](#) | [Change Country](#)

My Digi-Key | [Newest Products](#) | [Product Index](#) | [Supplier Index](#) | [Resources](#) | [USD](#)

Search [Live Online Chat](#)

Keywords:

In stock
 Lead free
 RoHS Compliant

Records matching criteria: 2,838,103

Audio Products

- [Accessories](#) (54 items)
- [Buzzer Elements, Piezo Benders](#) (57 items)
- [Buzzers](#) (1971 items)
- [Microphones](#) (527 items)
- [Sirens](#) (90 items)
- [Speakers](#) (396 items)

Battery Products

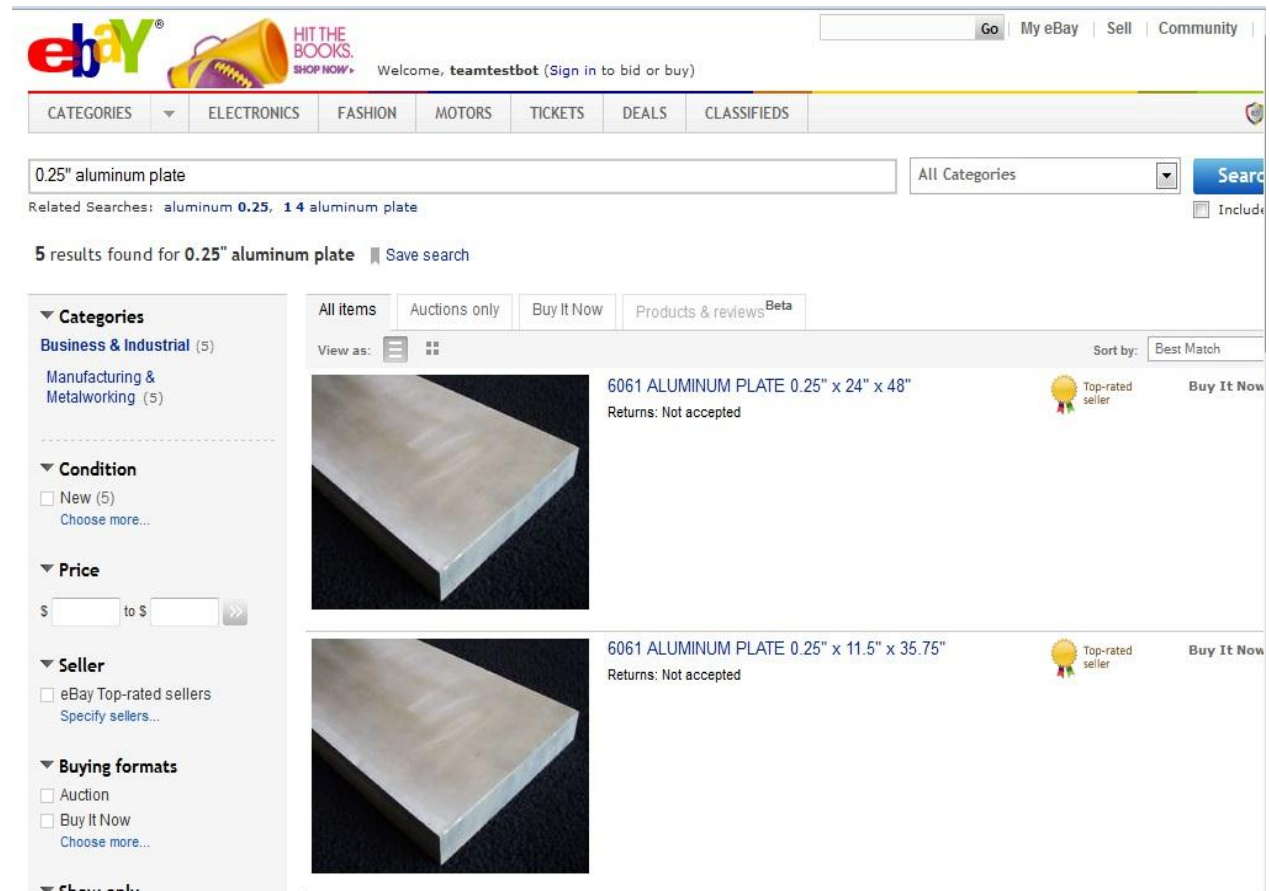
- [Accessories](#) (40 items)
- [Batteries Non-Rechargeable \(Primary\)](#) (310 items)
- [Batteries Rechargeable \(Secondary\)](#) (485 items)
- [Battery Chargers](#) (61 items)
- [Battery Holders, Clips, Contacts](#) (1061 items)
- [Battery Packs](#) (2620 items)
- [Cigarette Lighter Assemblies](#) (52 items)

Boxes, Enclosures, Racks

- [Backplanes](#) (47 items)
- [Boxes](#) (7639 items)
- [Boxes - Accessories](#) (522 items)
- [Boxes - Components](#) (1075 items)

Source it: Materials and Mechanical Parts

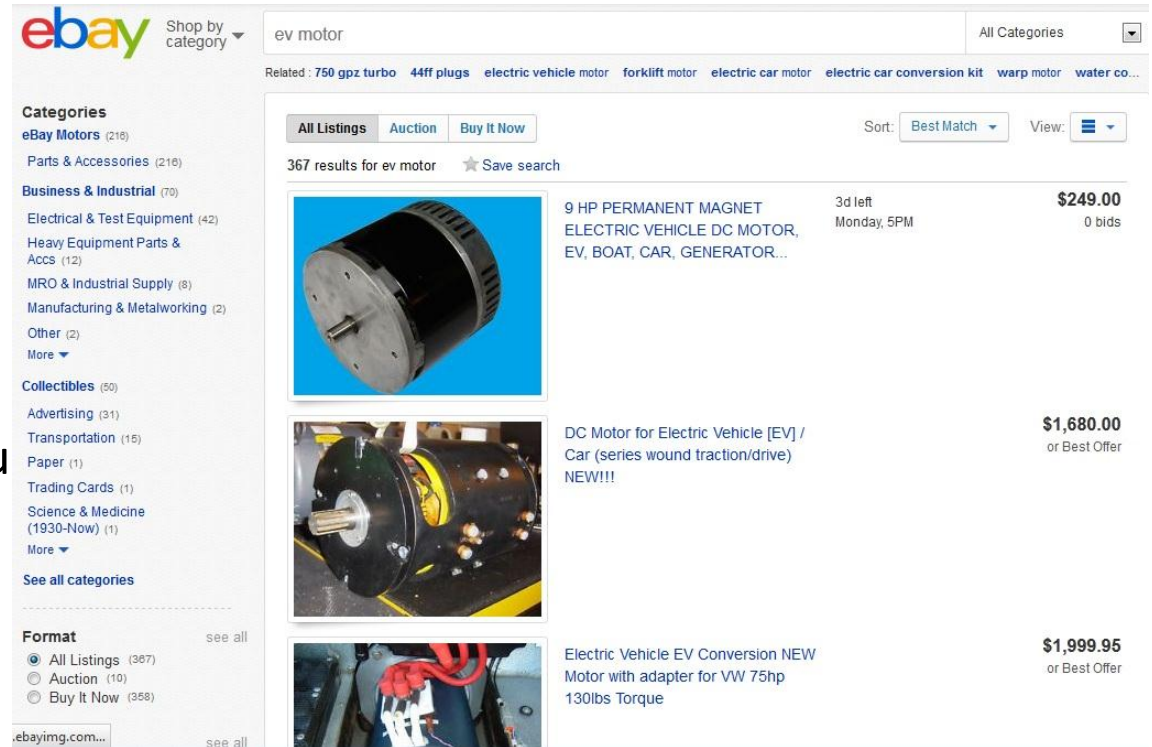
- **Materials and metals**
- Onlinemetals (onlinemetals.com)
- Onlinemetalsupply (onlinemetalsupply.com)
- Speedy Metals (speedymetals.com)
- eBay
 - Search by alloy, size, and descriptors
 - “Plate” “Sheet” “Bar”
- Interstate Plastics (interstateplastics.com)






The screenshot shows an eBay search results page for the query "0.25\" aluminum plate". The page features the eBay logo, a search bar with the query, and a navigation menu with categories like Electronics, Fashion, Motors, Tickets, Deals, and Classifieds. The search results are displayed in a grid format, showing two items: "6061 ALUMINUM PLATE 0.25\" x 24\" x 48\"" and "6061 ALUMINUM PLATE 0.25\" x 11.5\" x 35.75\"". Both items are listed by a "Top-rated seller" and include a "Buy It Now" button. The left sidebar contains filters for Categories (Business & Industrial), Condition (New), Price, Seller (eBay Top-rated sellers), and Buying formats (Auction, Buy It Now).

Source it: Did Someone Say Ebay?

- eBay is one of the most underestimated resources for builders, but it must be used cautiously.
 - Many keyword permutations
 - Sort by distance – don't accidentally order from China and wait 5 weeks because you sorted by Price Lowest.
 - Cross-check found parts with actual vendors to compare prices and shipping options
 - Shipping might be 90% of the parts cost (fee dodging!)



The screenshot shows an eBay search page for "ev motor". The search results are sorted by "Best Match" and show 367 results. The top three results are:

Image	Product Description	Price	Shipping/Availability
	9 HP PERMANENT MAGNET ELECTRIC VEHICLE DC MOTOR, EV, BOAT, CAR, GENERATOR...	\$249.00	3d left Monday, 5PM 0 bids
	DC Motor for Electric Vehicle [EV] / Car (series wound traction/drive) NEW!!!	\$1,680.00 or Best Offer	
	Electric Vehicle EV Conversion NEW Motor with adapter for VW 75hp 130lbs Torque	\$1,999.95 or Best Offer	

Source it: Materials and Mechanical Parts

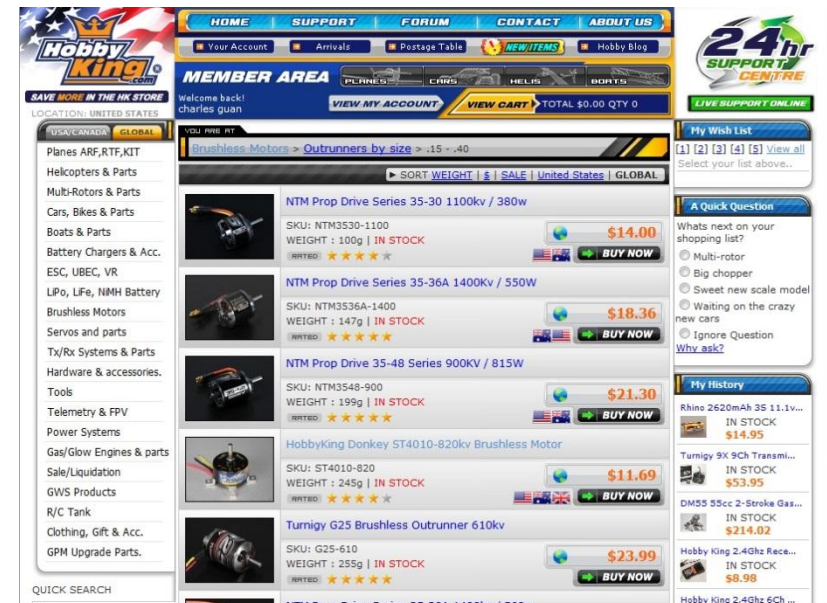
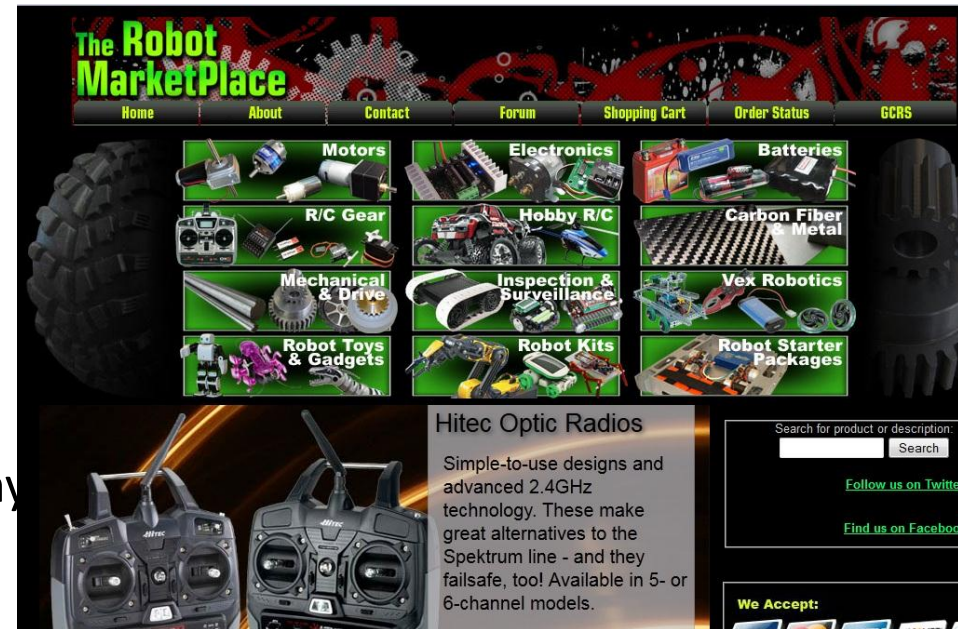
- **Surplus Center** (surpluscenter.com)
 - Most mechanical parts (chains, gears, shafts, collars, hubs), not so many belts
 - Semi parts, farm equipment
 - DC motors and gearmotors
- Surplus parts might not be to all your specifications, but they could be cheaper.
- **AlElectronics, Goldmine Electronics**
 - Electronics and small mechanical surplus
- **American Science and Surplus**
 - Elec & Mech surplus and hobby/craft supplies
- Others (Herbach & Rademan, Alltronics, M.E.C.I, Halted Surplus)

The screenshot shows the Surplus Center website interface. At the top, there's a navigation bar with 'SURPLUS CENTER BURDEN SALES CO.' and a phone number '1-800-488-3407'. Below this is a search bar with a 'GO' button and a 'View Items in Cart' link. A navigation menu lists various categories: PNEUMATICS, ELECTRICAL, ENGINES/AUTOMOTIVE, HYDRAULICS, POWER TRANSMISSION, WATER PUMPS, WHEELS/CASTERS, WINCHES, and MISC. A search section includes a 'Search for' field with a 'GO' button, a 'click here to see our NEW ARRIVALS!' link, and a 'Catalog Quick Order' section with an 'Enter an Item Number' field and a 'GO' button. A 'SECURE' badge is also visible. Below the search section, there's a 'SINCE 1938' banner and a 'Free Catalog | Tech Help | Product Index' link. The main content area displays a grid of products with images and descriptions:

- BERGER LAHR STEPPER MOTORS** (with a 'click image for more information' link)
- 2 X 13/16 SOLID RUBBER WHEEL** - \$0.79
- 2 SPOOL 12 GPM WALVOIL 1022A0025 HYD CONTROL VALVE** - \$109.95
- 59 HP KUBOTA V2403-M-T-EU4 TURBO DIESEL ENGINE** - \$3,995.95
- 13.4 HP VANMAR 2TIV70-HGE DIESEL ENGINE** - \$995.95
- 100 VAC 107 IN-LB STEPPER MOTOR 6.2A** - \$89.99
- 12 VDC 1.5" MARINCO**
- 12 VDC WIRELESS REMOTE CONTROL 7**
- 4.80X8.00-2.25 FLAT**

Source it: Motors and Actuators

- **Robot Marketplace:** Centralized vendor for most robot and electromechanical projects
 - Brush DC motors, chain-belt-gear, batteries, etc.
 - Created by a former Battlebots competitor; many products are geared towards larger robots, but there are many products for very small hobby robots.
- **HobbyKing:** Brushless motors, lithium batteries
 - Geared towards R/C models
 - Motors can be repurposed for other applications such as vehicle traction, generators.
 - Inexpensive lithium ion battery packs and chargers



Source it: Motors and Actuators

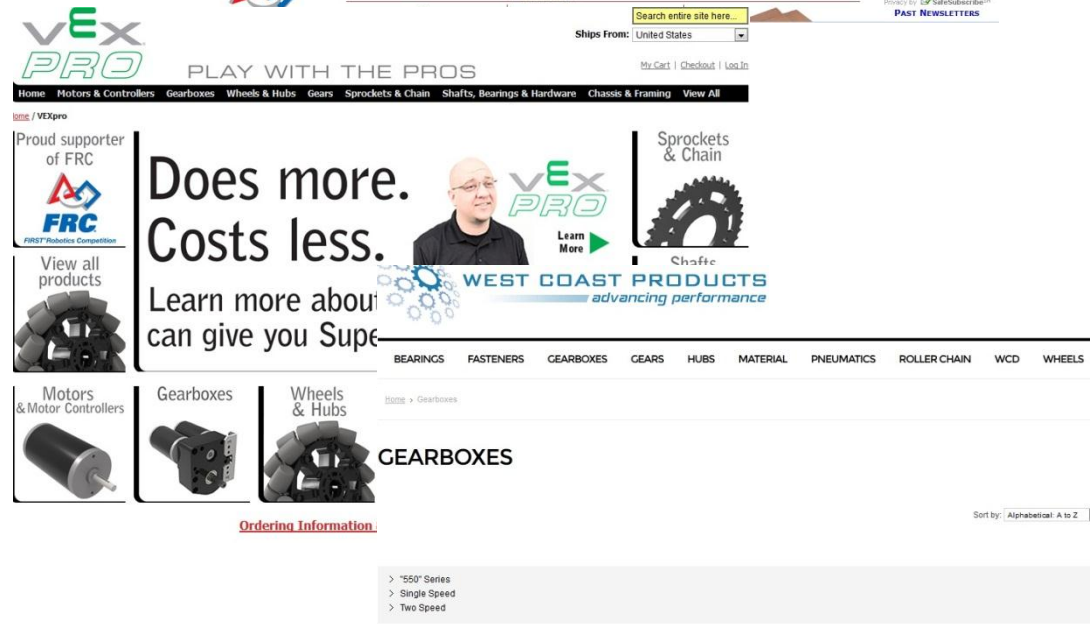
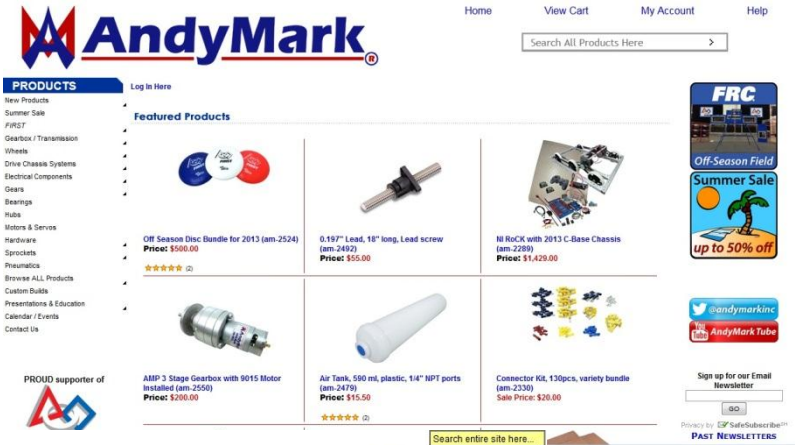
- **FIRST Robotics vendors**
 - Nationwide secondary school robotics program now has a network of vendors officially supporting it (I know, right?)
 - Inexpensive mechanical parts “Built to last the season” ...but cheap.

- **AndyMark**

- **Vex Pro**

- **West Coast Products**

- Effective source of power transmission products (chains, belts, shafts, gears, bearings, actuator parts...)



Source it: Motors and Actuators

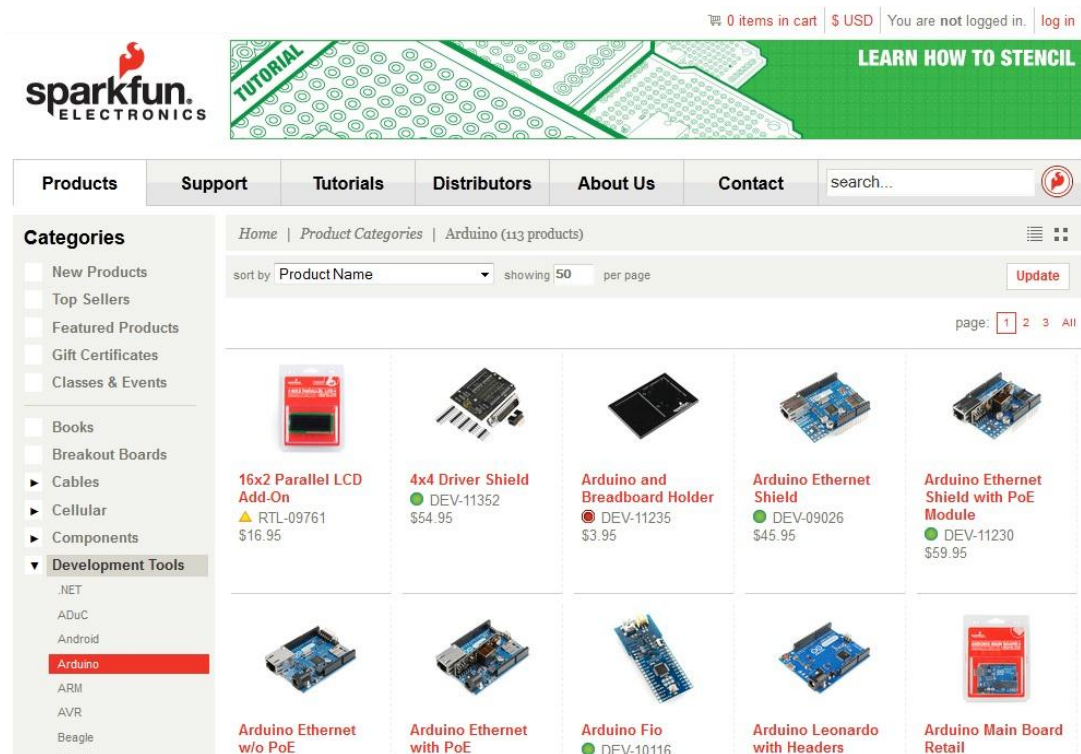
- **Small Robot Vendors**
- **Pololu:** Very small DC motors and gearmotors for little robot drives. Motor controllers and other control electronics. Robot kits and frames.
- **Solarbotics:** Similar market to Pololu.
- **Trossen Robotics:** Another general hobby robotics vendor with a wide selection of small and medium size motor controllers
- **ServoCity:** Anything to do with R/C servos used as robot actuators. Many different styles of hubs and adapters.

The image displays two screenshots of websites related to robotics and electronics. The top screenshot is the ServoCity website, featuring a navigation bar with 'Customer Login', 'Register', and 'shop online or call 620-221-0123'. A prominent banner advertises the 'HITEC X4 Eighty Multi-Charger' with a 'click here' link. Below the banner, various products are showcased, including 'Top Seller! ServoBlocks', 'NEW! - Digital Servo Gearboxes', 'BRAND NEW! Speed Controller', 'NEW! - High Voltage HS-430BH Servo', and 'BRAND NEW! 32P Aluminum Gears'. The bottom screenshot is the Pololu website, showing a search bar, navigation tabs for 'Catalog', 'Forum', 'Resources', 'Distributors', 'Ordering', 'About', and 'Contact'. A large 'elektor' magazine advertisement is featured in the center, with a 'SPECIAL OFFER!' to get free copies. The right sidebar shows a shopping cart with a subtotal of \$32.85 and a 'Check out' button. The left sidebar lists various product categories like 'Robot Kits', 'Electronics', and 'New Products'.

Source it: Controls and Sensing

- **Sparkfun Electronics**

- Established supplier of hobby electronics and supplies. Part of the open-source hardware community.
- Many different types of sensors – accelerometry and inertial, touch, buttons, pressure, temperature... with “breakout” boards for hard-to-use components
- Microcontroller development kits. More Arduinos than your body has room for
- Tutorials on EAGLE, surface mount soldering, programming in C, etc.



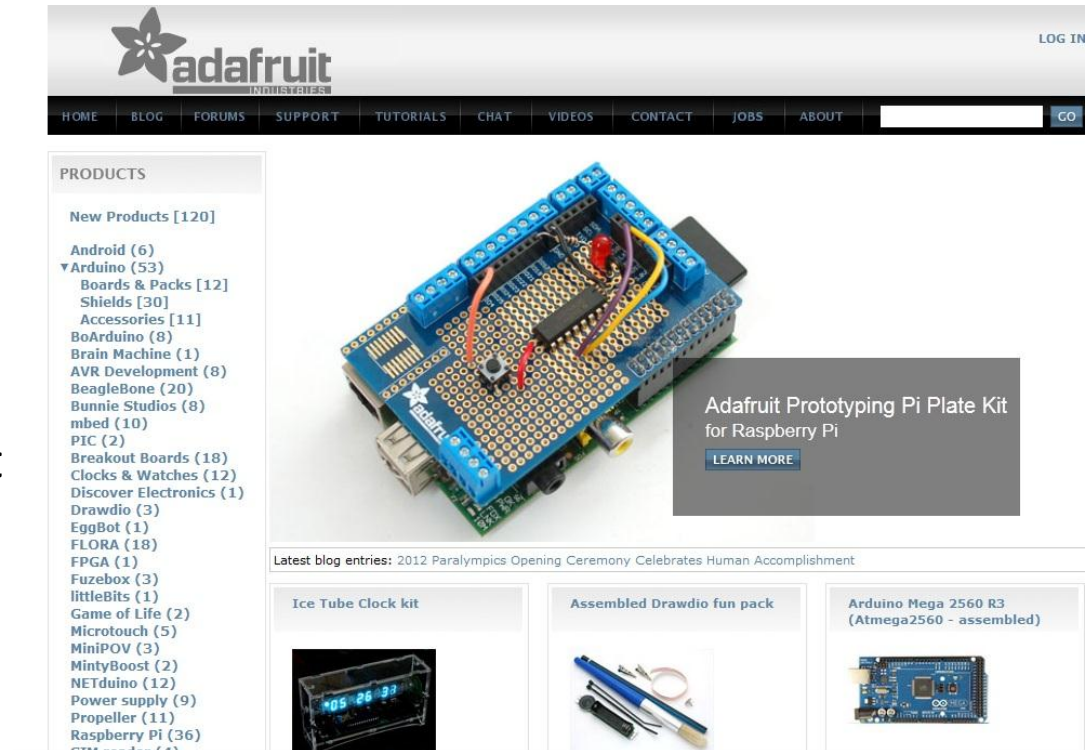
The screenshot shows the Sparkfun Electronics website interface. At the top, there is a navigation bar with the Sparkfun logo, a shopping cart icon showing 0 items, a currency selector set to USD, and a login link. Below the navigation bar is a banner for a tutorial titled "LEARN HOW TO STENCIL". The main content area is titled "Products" and "Support" with a search bar. The "Categories" sidebar on the left lists various product types, with "Development Tools" expanded to show "Arduino" selected. The main product grid displays 10 items, including:

Product Name	SKU	Price
16x2 Parallel LCD Add-On	RTL-09761	\$16.95
4x4 Driver Shield	DEV-11352	\$54.95
Arduino and Breadboard Holder	DEV-11235	\$3.95
Arduino Ethernet Shield	DEV-09026	\$45.95
Arduino Ethernet Shield with PoE Module	DEV-11230	\$59.95
Arduino Ethernet w/o PoE		
Arduino Ethernet with PoE		
Arduino Fio	DEV-10116	
Arduino Leonardo with Headers		
Arduino Main Board Retail		

Source it: Controls and Sensing

- **Adafruit Industries**

- Many hobbyist/maker contributed kits and open source products
- Arduino products and development boards
- Wearable electronics development products
- Tutorial system for basic and intermediate electronics skills (Adafruit Learning System)



The screenshot shows the Adafruit Industries website. The top navigation bar includes links for HOME, BLOG, FORUMS, SUPPORT, TUTORIALS, CHAT, VIDEOS, CONTACT, JOBS, and ABOUT. A search bar is located on the right. The main content area features a large image of the 'Adafruit Prototyping Pi Plate Kit for Raspberry Pi', which is a blue PCB with a breadboard and various electronic components. A text overlay on the image reads 'Adafruit Prototyping Pi Plate Kit for Raspberry Pi' with a 'LEARN MORE' button. To the left of the image is a 'PRODUCTS' sidebar with a list of categories and their counts, including 'New Products [120]', 'Android (6)', 'Arduino (53)', 'Boards & Packs [12]', 'Shields [30]', 'Accessories [11]', 'BoArduino (8)', 'Brain Machine (1)', 'AVR Development (8)', 'BeagleBone (20)', 'Bunnie Studios (8)', 'mbed (10)', 'PIC (2)', 'Breakout Boards (18)', 'Clocks & Watches (12)', 'Discover Electronics (1)', 'Drawdio (3)', 'EggBot (1)', 'FLORA (18)', 'FPGA (1)', 'Fuzebox (3)', 'littleBits (1)', 'Game of Life (2)', 'Microtouch (5)', 'MiniPOV (3)', 'MintyBoost (2)', 'NETduino (12)', 'Power supply (9)', 'Propeller (11)', 'Raspberry Pi (36)', and 'STM reader (4)'. Below the main image, there is a section for 'Latest blog entries' with three featured items: 'Ice Tube Clock kit', 'Assembled Drawdio fun pack', and 'Arduino Mega 2560 R3 (Atmega2560 - assembled)'.