



STEM LAB,
MAKERSPACE &
MACHINE SHOP
FUNDAMENTALS

A GUIDEBOOK TO
BUILDING THE
FOUNDATION FOR
YOUR GROWING LAB

INSPIRE. NURTURE. TEACH.

When building a STEM lab, makerspace or machine shop, many look to incorporate two distinct manufacturing technologies – additive and subtractive.

Whether building parts layer-by-layer or removing material from a larger piece of material through more traditional machining processes, both manufacturing methods are essential to preparing tomorrow's engineers, designers and problem solvers for their future careers.

How can you know which types of technologies are right for your lab? Ultimately, it depends on the learning objectives and desired outcomes of your program.

In this guidebook, we'll examine the fundamental additive and subtractive manufacturing technologies that make up the foundation of any STEM lab, makerspace or machine shop – **3D printers, CNC machines, laser cutters, 3D scanners, vacuum formers, printer/cutters, design software and more.**

PREPARE STUDENTS FOR CAREERS RESHAPED BY

3D PRINTING



Getting Started

Think about how you will ensure your 3D printer functions in a meaningful way at your school.

Will you use it to cover basic design principles? Teach product design? Provide exposure to the power of invention?

Choosing the Right 3D Printer

MATERIAL OPTIONS

What material properties does your part need to have?

PolyJet technology can produce small features and fine textures. More advanced PolyJet systems offer a variety of flexibilities, transparencies, colors, and a combination of the three.

Fused Deposition Modeling (FDM) technology prints with real thermoplastics like ABS, one of the most commonly used in the world. The result is tough, durable parts that can be tested and used in the real world.

High-end FDM systems can print with a multitude of thermoplastics that can withstand a wide variety of elements, from extreme temperatures to exposure to certain chemicals.

How will your part be used?

PolyJet's ability to create intricate parts and very fine feature details makes it a great choice for concept models as well as small, highly detailed models. FDM produces durable parts ready for end-use applications.

Do you care about your part's appearance?

If surface finish and aesthetics are critical, then PolyJet's very fine layer resolution and multiple material options make it a good choice. The FDM process creates more visible layer lines, but the uniformity of the layers in professional level systems still typically results in an aesthetically pleasing part.

EASE OF USE

While hobbyist 3D printers work well for teaching the basics of how the 3D printing process works, professional level systems are preferred for teaching design.

The ease of use and reliability allow students and instructors to focus on their designs – not the 3D printing process.

Professional systems vary in capability and price so it is important to consider other variables like material options and system reliability.

Know how much manual configuration is expected from the user throughout the printing process. More complex parts may require manual customization at the individual layer slice as the part prints. The more advanced the professional system, the greater control you will have over the print.

RELIABILITY

Dozens of 3D printing startups enter the market each year. Not all will make it. It's important to work with a manufacturer that can provide support in the short term and long term.

Short-term reliability comes down to consistency. High-end components used in professional level systems result in a much higher success rate in your prints, allowing you to have the confidence to print a large job over the weekend and know it will be ready and waiting for you on Monday morning.

Do you need a printer that will last two years? Ten years?

Hobbyist systems may become outdated or obsolete in a couple of years and replacement parts more difficult to obtain.



Stratasys
3D Printers

Professional level systems are designed to last for a much longer period. Many who own professional systems get ten years or more out of their investment.

FACILITIES REQUIREMENTS

Typically, the more advanced the 3D printer, the greater the facility requirements. Some systems require more power to run, while others expose users to dangerous fumes and chemicals.

Others are designed for offices or classrooms and can simply plug into a regular wall outlet. Consider where the system will be located and if it requires a full-time dedicated operator.

COST OVER TIME

While the upfront cost of a 3D printer is an important factor in the decision-making process, ongoing expenses should be considered as well.

The obvious ongoing expense is material. Know if the machine

comes with any model or support material, what the material costs, and how often it will need to be replenished. The same goes for miscellaneous consumables such as bulbs, binders, and brushes. Check with the manufacturer or reseller to get the full picture of a system's consumables.



Another primary cost is system operation and maintenance. Does the system require a dedicated professional to manage operations? What does it cost to maintain the system each year? If the machine has a service contract, are there any parts that are not covered under the contract?

The answers to these questions will help you compare apples to apples when considering different 3D printer packages. ■





UNLEASH THE POWER OF

CNC MACHINING

Getting Started

Will your students use a CNC machine as a tool to complete a design project or are you training workforce-ready machinists?

Integrating CNC machining into your program does not necessarily require large industrial machines. Industrial equipment - and the software that runs it - has a bigger learning curve as well as fewer safety features, which are critical for novice users.

Uncovering What Works Best

MACHINE TYPE

Standard CNC machining processes include milling / routing and turning.

Which is right for you? That depends on the application.

Routers, Engravers & Mills

Routers are typically less expensive than mills and feature larger table sizes, but are less rigid than a mill. A CNC router is often used to cut parts out of plastics or wood, but some systems come equipped with spindles that can cut non-ferrous metals such as brass, copper,

and aluminum. If you need to cut iron or steel, you will most likely need a mill.

Some CNC routers may have specialized heads for specific applications. For example, if you are looking to cut out circuit boards, you may want to consider a machine that utilizes a “floating head” design that can compensate for materials that aren’t perfectly flat.

A mill typically has a smaller table, but is heavier and more rigid than a router. These features allow it to cut materials, like steel and iron, more accurately.

When training machinists, consider a mill based on its prevalence in the industry. When introducing students to CNC machining, consider smaller CNC machines designed for safety and ease of use.

Turning

Another CNC process widely used in manufacturing is turning. This is when a piece of material rotates on a cylinder and a computer controls a cutting tool that carves or removes material from the rotating piece.

This is another good skill to teach the next generation workforce.

SOFTWARE

A fundamental understanding of the software required to control a CNC machine is critical to student success.

There are numerous parameters that need to be set correctly in order to achieve the desired result.

standard CAD/CAM software, consider Wizard-based CAM software that guides students through the CNC process.

This prompts learners through each step of the process to set up a part.

For example, once a student inputs a material type, the

simulation of a CNC machine. This allows students to make design and tool setup mistakes without the added costs of wasted materials and reduces the frustration of making mistakes on a real machine.

After your students have a solid fundamental understanding of how the system works and what each parameter does, they will be ready to take on more industrial software.

SAFETY

When teaching students how CNC machining works, the equipment they learn on should be safe, easy to use and rely on software that teaches the design process, allowing them to fail fast and learn from their mistakes.

Look for fully enclosed machines that will protect students if they make a mistake that sends sharp materials airborne. ■

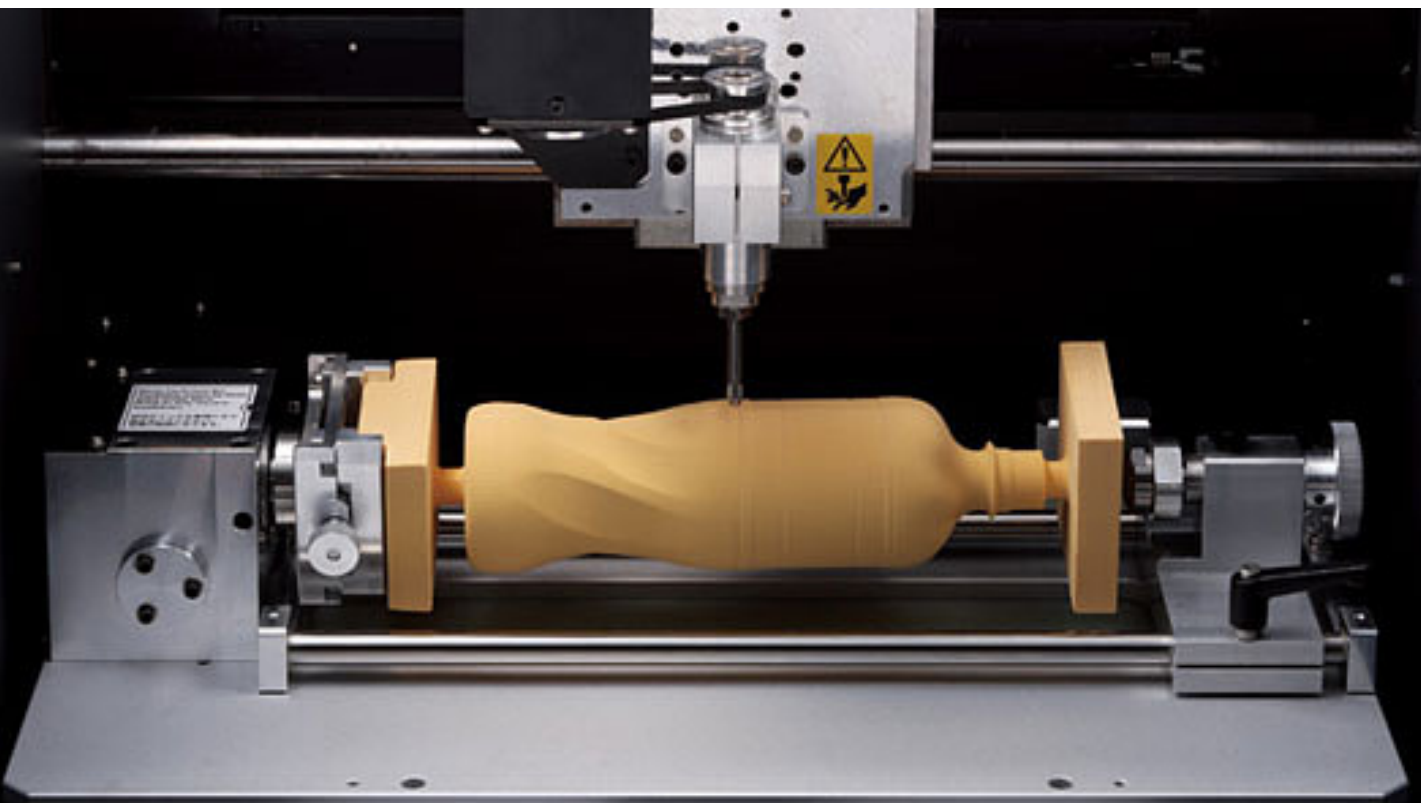
MANY STUDENTS
STRUGGLE WITH THE
COMPLEXITY OF
INDUSTRIAL CAM
SOFTWARE AND
CAN BECOME
EASILY FRUSTRATED

While it makes sense for students to learn CAM software that is used in industry, many students struggle with the complexity of industrial CAM software and can become easily frustrated.

Instead of starting with industry

software calculates the feed rate and spindle speed of the machine to teach how quickly the tool should move through the material.

Also consider software with controls that allow for virtual



IGNITE CREATIVITY THROUGH

LASER CUTTING

Getting Started

Integrating laser systems into K-12 schools, trade and vocational schools, colleges and universities can help illustrate complex design and engineering principles to students at all levels.

Selecting the right laser system for your program comes down to the materials you plan to cut, ease of use, and costs over time.

Cutting Through the Options

EASE OF USE

Systems that offer the ability to select preset materials from a database drastically reduce the learning curve. There is no need to set the speed, power and pulse rate.

Instead, simply select the material you're using, input the material thickness, and watch the print driver do all the calculations needed to give you the best cut.

This allows new users to get up and going rapidly and reduces the chance of errors.

At the same time, control over all of the parameters is important for power users. Find a system that can offer both in one driver to satisfy all of your users' needs.

OPTICS PROTECTION

Laser systems should have optics protection from dust, debris and other invisible contaminants to prevent frequent replacement, resulting in system downtime.

While many systems boast optics protection, look closely at how this protection is designed.

A system that constantly blows

clean air over the optics instead of simply under the optics keeps the lens cleaner longer, which reduces lens cleanings and increases lens life.



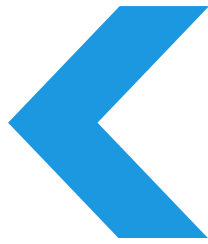
Universal Laser Systems PLS6.150D

LASER WATTAGE

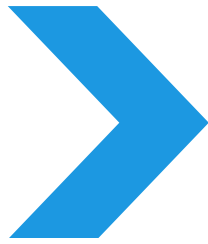
The general rule of thumb is every 10W provides a tenth of an inch of cutting depth, so think about:

- what material you will cut most commonly; and
- the thickest material you plan to cut.

Consider your needs now and in the future. If you project you will need to cut thicker materials as your program grows, look into laser systems that allow you to easily swap out the laser tube so that you can have a more powerful system down the road.



CONSIDER YOUR NEEDS NOW AND IN THE FUTURE



COST OVER TIME

The ideal average laser cartridge lifespan is five to six years before it needs to be replaced.

Companies that manufacture their own replacement laser tubes can typically provide a much lower cost replacement than those that outsource.

Before you buy a system, understand how much it will cost to replace the laser cartridge and whether it's easy enough to replace yourself or if a technician is required.

Also, look for systems that offer longer warranties on their laser cartridges in case of unexpected issues. ■



REVERSE ENGINEER DESIGNS WITH

3D SCANNING

Getting Started

What level of detail do you need to achieve with your scan data?

What size objects do you plan to scan?

Are you looking to collect and archive scan data, scan and print, or reverse engineer parts?

Finding the Right Fit

SCANNER RESOLUTION

Higher resolution scanners are typically more expensive. High resolution scans also produce massive amounts of data, requiring a higher end computer. Scanners with lower resolutions typically have a larger scanning area and depth of field, allowing you to accurately scan a larger area in less time – all with lower demand on your computer.

There is a misconception that you should purchase a scanner with the highest resolution you can afford. Think about the types of objects you plan to scan and

the level of detail you want to achieve so you don't waste money on resolution you don't need. For instance, if you plan to scan the outside of a vehicle, you may not need feature details down to the width of a human hair.

In some cases, an application may require multiple scans in different resolutions. You may want to use multiple scanners within the same project in order to capture the overall shape of a large object quickly, then go back and scan areas of interest in higher resolution for more detail. If this is the case, look for

bundles that include a lower and higher resolution scanner in a single package at a reasonable price.



HANDHELD VS. TABLETOP

Should you purchase a table top scanner that sits on a tripod, or a handheld scanner? The size of the part you wish to scan plays a role in answering this question.

If you primarily plan on scanning parts that are smaller than the size of a basketball, a tabletop scanner with an automated turntable is a good solution.

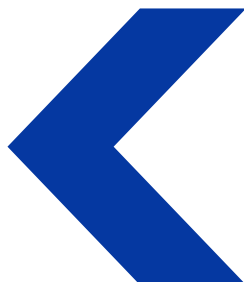
These scanner configurations allow you to place a part on the turntable and select the number of scans. The scanner then does the work of rotating the part and stitching the scans together, while leaving your hands free to do other things.

Large objects are typically better suited for a handheld scanner so you can continue to move around the part while scanning. A hand held scanner is also often more versatile because it can scan both small and large objects easily.

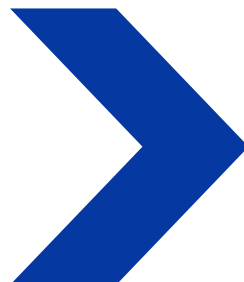
SOFTWARE

Most scanners are software agnostic leaving you with an array of options to choose from.

If you want to alter a scanned object, look for software with a Scan-to-CAD workflow. For example, say you have a broken part you need to fix. You will want



MOST
SCANNERS ARE
SOFTWARE
AGNOSTIC



What is your end goal? If you aim to produce exact replicas of objects, look for software with a Scan-to-Print workflow. Once an object is scanned, the software will help you clean up the mesh so that you have a watertight mesh ready for 3D printing.

to scan the part, reverse engineer and rebuild it using CAD software, and then either reproduce it yourself or outsource its reproduction. ■



COVER ALL YOUR PACKAGING NEEDS WITH

VACUUM FORMING



Getting Started

What are your packaging needs?

What power is available in your makerspace?

Determining Your Users' Needs

POWER REQUIREMENTS

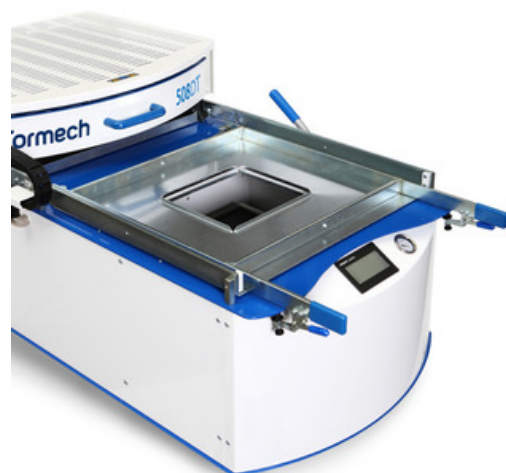
Pay attention to the power requirements of the system you are considering. Since vacuum formers need to get very hot, they typically require at least 220V single phase power. This means they will not simply plug into a standard power outlet. If you are not sure of the power requirements, you can usually find this information on the machine's datasheet.

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HEAT ZONES

The number of heat zones in a system corresponds with the ease-of-use of a system. A plug and play single zone systems is easy to operate and experiment with, making it the perfect solution for hobbyists and first time users. More heating

zones offer greater range of control to form challenging shapes and materials. Larger systems will boast four, six and – on large format vacuum formers – 15 heat zones. ■



CREATE INCREDIBLE DESIGNS WITH

PRINTERCUTTERS

Getting Started

There are several questions you should ask yourself when evaluating your options for a large format printer/cutter.

How do you want your system “inked up”? What material do you wish to use? How vivid must your imagery be?

Customizing a Solution for You

OUTPUT SIZE

How big are the banners, posters or packaging designs you need to print? Most commonly systems will accept media that is 30, 54 or 60 inches wide. One advantage of selecting a larger size system is the ability to run two banners side by side on the same media, which achieves significant cost savings.

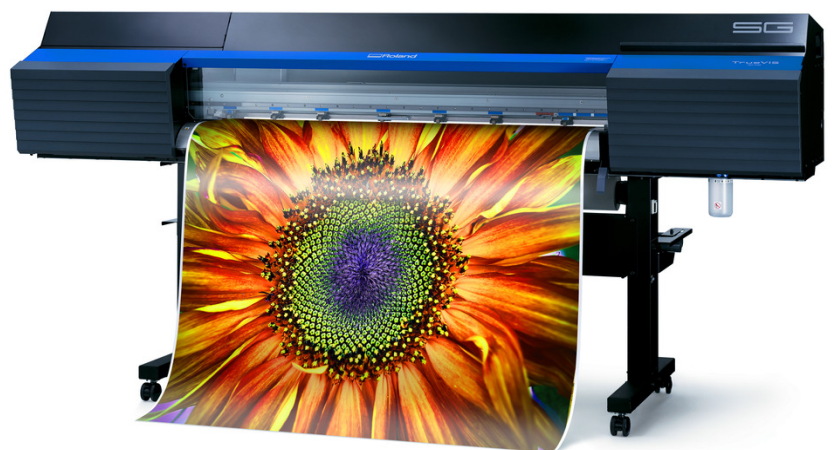
INK VERSATILITY

It is important to think about how you want your systems inked up because this is something that cannot be

changed down the road. What you decide now is exactly how the printer can be used for its lifetime.

If the machine you are looking at

has a four channel setup, this will be a CMYK setup. This is the most popular choice and works for a wide variety of applications. For more control over color consider a machine with eight channels.



Roland TrueVIS SG Series Printer/Cutter

While these can be setup for dual CMYK, many users purchase these for their ability to load CMYK with light cyan, light magenta, light yellow, and light black. In some machines there is also the option for specialty inks such as white or metallic. These customized setups allow for more vibrant colors with less banding for a smoother, more realistic look.

CHECK TO SEE
IF THIRD PARTY
MEDIA
PROVIDERS
WILL SUPPLY
MEDIA PROFILES
FOR YOUR
MACHINE

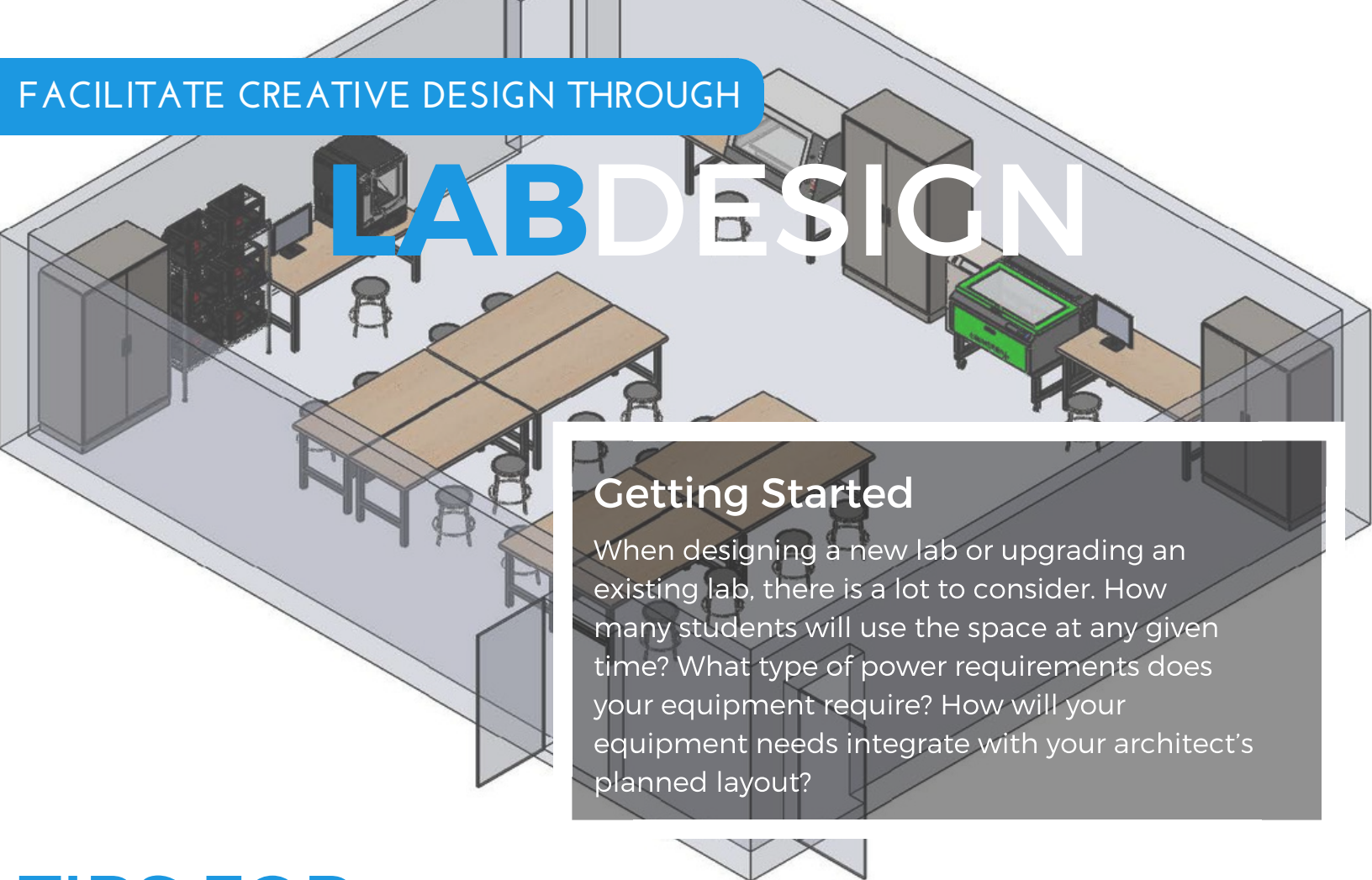
MEDIA OPTIONS

There are a variety of media options to choose from, including banner material, backlit film, canvas, heat transfer material, removable fabrics, vinyl, static cling, and more.

Often the manufacturer of your print-cut system will offer this wide variety and the system will have preset media profiles included for optimal print quality.

If you choose to use media from a third party, check to see if they will provide a media profile for your machine. Otherwise you may have to spend time creating one yourself. ■





Getting Started

When designing a new lab or upgrading an existing lab, there is a lot to consider. How many students will use the space at any given time? What type of power requirements does your equipment require? How will your equipment needs integrate with your architect's planned layout?

TIPS FOR DESIGNING YOUR MAKERSPACE

SPACE UTILIZATION

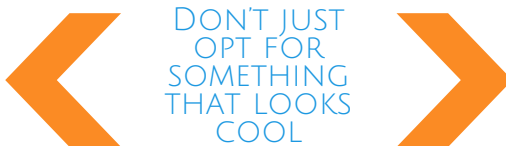
How you plan to use the space will determine your spatial flow. Will your lab be used for design and fabrication, or will the design work be completed in a separate space from the fabrication equipment?

DIRTY VS. CLEAN

It's recommended you separate dirty from clean equipment if possible. If not, you'll need to consider alternative equipment options.

NOISE CONTROL

The last thing you want is a noisy CNC machine running right where you are teaching students. It's easy to minimize noise disruptions with a little planning in advance.



DON'T JUST
OPT FOR
SOMETHING
THAT LOOKS
COOL

POWER AND ELECTRICAL REQUIREMENTS

It's important to read equipment datasheets in detail to understand power requirements before you purchase anything. Are you

working with an electrician? Specialized power cannot be changed after it's put in, so this will affect the timeline of when you finalize your lab layout.

FURNITURE

Consider furniture with the right storage options and durability to fit your needs. Don't just opt for something that looks cool.

DESIGN FOR MOBILITY

Mobile furniture and equipment offers an entirely new level of customization, which can change the overall flexibility and functionality of your lab. ■



INSPIRE NEW IDEAS WITH

DESIGN SOFTWARE

Getting Started

Design software is the linchpin that ties all hardware – 3D printers, CNC machines and laser systems – together. While these modern technologies will evolve over time, the design process is a steadfast skill students must master to operate any type of machine today and in the future.

Often you'll find free 3D design software available in education, but what does "free" really mean? How do support, training, and industry certification factor in and when will your "free" contract expire?

Discovering Endless Possibilities

CAPABILITIES

Design software should do more than teach how to create a mechanical part. It should take designs through every step of the product lifecycle process to show students what is required to bring a product to market.

In addition to 3D CAD design, look for capabilities like simulation for virtual analysis and testing of a part, sustainability testing that identifies comparable materials in an original design that have a smaller environmental footprint,

and design tools for creating product packaging and marketing materials.

SUPPORT & TRAINING

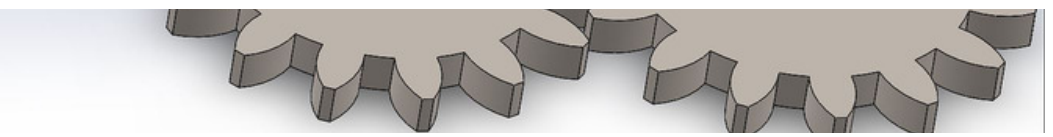
Consider software that is fully supported with online help, an active user community and a variety of online resources and tutorials.

Understand the support process

so you know what phone number to call if you experience any IT issues after installation.

Consider the available options as you seek to fine tune your skills. Are there training courses available to help you focus on fundamental design and modeling skills and concepts?

What about free exams to help you teach design skills or prepare students for certification?



CERTIFICATION

In today's competitive job market, CAD professionals need every advantage they can get. Arm your students with recognized industry certifications so that they are more attractive candidates

STUDENT SUCCESS

Mastering design software is a significant time commitment. When you invest time in teaching students this software, make sure they get the most out of the experience.



CAD
PROFESSIONALS
NEED EVERY
ADVANTAGE
THEY CAN GET

during the hiring process and can hit the ground running once hired by their dream company.

Look for software that provides you with all the resources you need to adequately prepare your students for and successfully administer the certification exam. This could be in the form of general guidelines, tips sheets, and practice exams.

Run search queries on job listing websites in your area for each CAD software package you are considering to see how many employers require which software skill sets and certifications.

This is the best indication of the employability of your students after they leave your classroom. ■



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