Introduction to 3D Printing

INSTRUCTOR GUIDE

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Course Description

Course Goal

To enable and prepare learners to get hired as entry-level 3D Printing Technicians.

Course Materials and Delivery Note

This course consists of 19 lessons that should be delivered in order to learners. It is important to note here that one lesson does not equal one class period. Each lesson is delivered to learners in any number of class periods. It may only take one class period to deliver a particular lesson. Or, it may take 2-3 class periods to deliver one lesson. The scheduling is flexible and up to your school and you.

Course Overview

The main purpose of this course is to prepare learners to be 3D Printing Technicians. Learners are assigned CAD files to use throughout the course as they learn how to fulfill a part request. Learners practice the workflow from start to finish. They learn how to analyze a new file, orient the file in 3D Sprint for the Figure 4 and create supports for it. They then prepare that file for printing. Once learners have worked through the entire process, a final project is assigned where they complete the entire process.

Learners should have some knowledge of CAD and be able to open an .stl file in a CAD program. The purpose of this course is not to teach them how to design or create a CAD model that they can print, nor to teach them how to use the Figure 4 printer, but to enable them to fulfill a part request using the Figure 4 Standalone printer.

This course is designed for up to 20 learners in each session with one Figure 4 printer and 3D Systems materials. Ideally, each learner should have their own computer/laptop, but two learners can share a single computer. The desks, laptops, and printers should be located in the same physical location.

Each class will include all or some of the following delivery components, depending on the day's lesson:

- PowerPoint slides with lecture
- Videos
- Handouts (in addition to the Learner Guide)
- Questions
- Quizzes
- Project Work - Hands-on Exercises
- Assignments (optional homework for further study)

Target Audience

The target audience for this course consists of university students who are interested in becoming 3D Printing Technicians/Operators. Learners are most likely young and are expected to get a job as a 3D Printing Technician upon graduation. They have taken other courses at the school, but this course is their first exposure to 3D printing and the Figure 4 printer. They may or may not have taken CAD training, but most likely will know how to design basic 3D geometry using a CAD system. They will have little to no knowledge of 3D printing apart from what they may have come across on social media. This course will be offered as one of the subjects sometime during their time at the school. It may be mandatory for some programs and optional for others.

Figure 4 3D Printing Technician

As a 3D printing technician, you will oversee the printing process and offer recommendations on what products a company can produce via a 3D printer. You may also work with the product management team on product development, including establishing design processes.

Technicians, or Service Engineers, are sought after by 3D printing companies and their clients to operate and maintain the many 3D printers in the Additive Manufacturing (AM) industry. A technician role requires learning how to operate 3D printers and their print preparation software, which is unique to each manufacturer. Additional tasks may include maintenance and repair, new feature integration, testing and documentation, and advising customers on industry-specific 3D printing applications. As a result, hands-on experience with 3D printers and CAD software will be highly beneficial when applying to a 3D Printing Technician or service engineer position.

Prerequisites

Prior to taking this class, learners must:

- Be able to perform simple design skills in a CAD program
- Be familiar with basic metrology concepts
- Have some knowledge or experience with:
    - Electrical and mechanical equipment
    - Manufacturing processes
    - Industries/verticals

Course Objectives

1. **Distinguish between 3D printing technologies in terms of process, materials, and applications.**
    - Explain what 3D printing is.
    - Explain the benefits of 3D printing.
    - Describe the different additive manufacturing technologies and their unique benefits.
    - Identify the industries and applications that use 3D printing.
2. **Explain the entire process of fulfilling a part request using the 3D Systems Figure 4 Standalone printer and material.**

    Step 1: Select/Confirm the Material and Printer
    Step 2: Import, Examine, and Repair the Part File
    Step 3: Orient the Part and Create Support Structures
    Step 4: Print the Part
    Step 5: Post-Process the Part
    Step 6: Inspect the Part
    Step 7: Ship the Part
3. **Prepare a 3D model for successful printing including orientation and creating support structures.**
    - Import a part file into 3D Sprint.
    - Make basic repairs to a part file.
    - Orient a part file on the platform.
    - Create supports for a model.
4. **Print a part with the Figure 4 Standalone printer that meets required specifications.**
    - Identify the parts of a Figure 4 printer and their functionality.
    - Describe 3D Systems Figure 4 materials and their properties.
    - Select or confirm the appropriate material to use for a requested part.
    - Perform work in a safe manner and adhere to safety programs, processes, and procedures.
5. **Describe regular and preventative maintenance on the Figure 4 Standalone 3D printer.**
    - Be aware of service maintenance plans and procedures and the role of the printer technician regarding those plans and procedures.
    - Be aware of troubleshooting procedures and the role of the printer technician when troubleshooting.
6. **Perform post-processing and finishing of 3D printed parts.**
    - Perform basic inspection operations on a printed part.
    - Describe various finishing options for Figure 4 printed parts.
    - Clean a Figure 4 printer, platform, and part after printing.
    - Recognize the job task of packaging and shipping the finished part.
7. **Maintain up to date knowledge of the 3D printing industry through research.**
    - Locate 3D Systems printer and material information.

Printer Technician Workflow

Step 1: Select/Confirm the Material and Printer

Step 2: Import, Examine, and Repair the Part File

Step 3: Orient the Part and Create Support Structures

Step 4: Print the Part

Step 5: Post-Process the Part

Step 6: Inspect the Part

Step 7: Ship the Part

Course Agenda

Lesson 1: Introduction to 3D Printing
Lesson 2: 3D Printing Technician Workflow
Lesson 3: 3D Printing Technologies and Applications
Lesson 4: Material Properties
Lesson 5: 3D Systems Figure 4 Standalone Printer
Lesson 6: Designing for 3D Printing
Lesson 7: 3D Sprint Demonstration
Lesson 8: Workflow Step 1: Select/Confirm the Material and Printer
Lesson 9: Workflow Step 2: Import, Examine, and Repair the Part File
Lesson 10: Workflow Step 3: Orient the Part and Create Support Structures
Lesson 11: Workflow Step 4: Print the Part
Lesson 12: Workflow Step 5: Post-process the Part
Lesson 13: Workflow Step 6: Inspect the Part
Lesson 14: Secondary Processes
Lesson 15: Maintaining and Troubleshooting Figure 4 Standalone
Lesson 16: Course Summary
Lesson 17: File Prep Lab
Lesson 18: Print Lab
Lesson 19: Project Reports and Final Quiz

Course Evaluations

At the end of the course, please remind learners to complete the course evaluation. The evaluation is their chance to provide feedback on the course and help us improve it for future learners.

Course Evaluation for Learners: http://3dsyste.ms/eval

As the instructor, we'd like you to also complete a special evaluation. We value your feedback. Thank you for your time.

Course Evaluation for Instructors: http://3dsyste.ms/instructoreval

Classroom Setup Instructions

Classroom Setup - Perform Two Weeks Before First Delivery

1. At least 10 laptops should be in the lab, each with its own power (or sufficient) source and mouse.
2. Install 3D Sprint on every laptop in the classroom (or make sure it's already installed).
3. Connect each software application to the printer in that lab, and to the correct material being used. You will explain how this is done during class (there's a video as well), but the learners do not need to do this in class.
4. Have access to a Figure 4 Standalone printer with the ability to print, manage, perform regular maintenance (with supplies available), and perform basic post-processing (with supplies available).
5. Make sure the projector is set up and you can project your PowerPoint slides. Also make sure the videos appear well enough when they're projected. Many lessons contain videos directly on the PowerPoint slides.
6. Have all required files; see the **Files List** document or the section on **Files** in this document.
7. Determine and set up the best method for getting files to each learner. For example, copy **Learner Files** to each laptop or a usb drive that can be handed out.
8. Print a **Learner Guide** for each learner.
9. 3D Print the parts listed in the **Parts List** document or the section on **Parts** in this document.

Course Materials

1. Update slide 2 of Lesson 1 (Lesson 1 Introduction to 3D Printing….pptx) to include your name, image (optional), and basic teaching background.
2. Update slide 3 to include the dates and times of all lessons, and when the course begins and ends. You may want to identify which lessons are covered on which dates, and when labs will be (especially for the Final Project).
3. Review the course materials, taking notes, as needed, to prepare for delivery.
4. Make sure you have Learner Guides printed or available to learners.

Classroom Setup – For Each New Class

Before each class starts, you must:

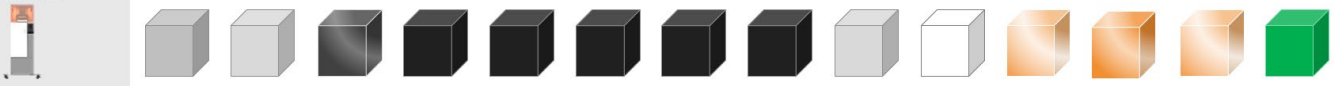
1. Make sure the printer is clean and powered up.
2. Turn on all hardware used in the class (laptops, projector, printer, curing unit) and make sure they're properly working.
3. Attach your laptop to the projector and make sure it is working. Open the PowerPoint file for this lesson's lecture.
4. Review the lesson's exercises and how the lesson will flow. Make yourself comfortable with the material.

Post-Classroom Instructions – After Each Class

When class is over, you must:

1. Clean and re-setup the printer and area.
2. Shut down all of the hardware unless another class will be taught soon.

Figure 4 Materials

Family	Rigid				Flexible		Rubber		Molding	Medical		High Temp	Molding	Casting
Key Feature	Ultra-Fast	Lowest Cost	Blk.Trans.	Snap-Fit	Polypropylene-Like		Low Rebound		Masters	White	Translucent	300°C	EZ-Shatter	Patterns
Biocompatibility				Yes			Yes	Yes	Yes	Yes	Yes			
Prototypes or Functional Parts	Prototyping			Functional	Prototyping		Functional		Elevated-Temp Functional Parts					Production
Outdoor UV Stability Tested			Outdoor			Outdoor		Outdoor		Outdoor			Sacrificial	
Material and Printer Compatibility	TOUGH GRY 10	TOUGH GRY 15	TOUGH BLK 20	PRO BLK 10	FLEX BLK 10	FLEX BLK 20	RUBBER BLK 10	RUBBER 65A BLK	JEWEL MASTER GRY	MED WHT 10	MED AMB 10	HI TEMP 300 AMB	EGGSHELL AMB 10	JCAST GRN 10
Standalone														

Lab Setup and Safety

Users should always wear closed-toed shoes and full-length pants. Be sure to let learners know. Enforce this rule.

Learners should bring an extra set of clothing to each lesson they'll be near the printer.

For Figure 4 Standalone safety information

Access this information here:

http://infocenter.3dsystems.com/figure4standalone/user-guide/safety

Lab Safety Requirements

Your lab setup should include the following:

1. Cleaning stations

   These are critical for everyone's safety.

   a. An eye wash station with running water

   b. Post-processing and cleaning station

      i. Tub of IPA (isopropyl alcohol) or other solvent for washing the part and platform (label is "Wash" or "dirty tub")

      ii. Tub of IPA (isopropyl alcohol) or other solvent for rinsing the part and platform (label it "Rinse" or "clean tub")

2. Protective Equipment

   Have plenty of protective equipment available

   a. 100% nitrile gloves, sufficient supply for regular use

   b. Protective glasses for each learner, plus extras

   c. Splash-resistant lab coats or equivalents

   d. Users should always wear closed-toed shoes and full-length pants

3. Tools

   Gather tools used after printing parts

   a. 2 tubs, mentioned above

   b. Plenty of IPA

   c. Extra towels, paper towels

   d. Hazardous waste garbage cans

   e. Punch tool

   f. Platform scraper

   g. Platform-cleaning fixture

   h. Cookie sheets (lightweight metal flat sheets) or aluminum tray

Safety Symbols and Definitions

The following are safety symbols that are common to 3D Systems guides. Some or all of these symbols may appear in this guide and/or in other Figure 4 Standalone documentation.

CAUTION: INDICATES THE POSSIBILITY OF LOSS OF DATA OR DAMAGE TO EQUIPMENT.

WARNING: INDICATES THE POSSIBILITY OF INJURY TO PERSONNEL.

HARMFUL IRRITANT WARNING: INDICATES THAT SKIN OR EYE IRRITATION COULD RESULT WHILE EXPOSED TO A CHEMICAL COMPOSITION

EYE PROTECTION: INDICATES THE NEED FOR EYE PROTECTION.

WEAR GLOVES: WEAR THE APPROPRIATE GLOVES WHEN REQUIRED. FOR EXAMPLE, WHEN TOUCHING SURFACES THAT MAY CONTAIN OR HAVE BEEN EXPOSED TO MATERIALS, WEAR NITRILE GLOVES. HEAT GLOVES ARE NECESSARY WHEN TOUCHING SURFACES THAT MAY BE HOT TO ENSURE BURNS DON'T OCCUR.

HOT SURFACE HAZARD: A HOT SURFACE IS ACCESSIBLE IN THE VICINITY OF THIS SIGN OR BEHIND THE ACCESS PANEL. AVOID CONTACT. HOT SURFACES CAN CAUSE BURN INJURY OR FIRE. ALLOW SURFACE TO COOL BEFORE TOUCHING. ACCESS PANELS ARE FOR SERVICE ONLY AND SHOULD BE OPENED ONLY BY CERTIFIED SERVICE PERSONNEL OR TRAINED MAINTENANCE PERSONNEL.

ULTRAVIOLET RADIATION: INDICATES THAT UV RADIATION IS PRESENT.

NOTE: A note signifies important information but not information of a critical content.

Material Handling and Safety

Refer to this web site for current information:
http://infocenter.3dsystems.com/figure4standalone/user-guide/safety/material-handling-and-safety

NOTE: For complete safety information and instructions for use, please read the SDS and User Guide for the Figure 4 resin you are using. These documents are packaged in with each bottle of print material.

HARMFUL IRRITANT WARNING: ALWAYS WEAR CHEMICAL-RESISTANT GLOVES (SUCH AS NITRILE GLOVES), GOGGLES, AND PROTECTIVE CLOTHING WHEN HANDLING PRINT MATERIAL. AVOID SKIN CONTACT. AVOID BREATHING IN PRINT MATERIAL FUMES.

- Always practice standard lab hygiene and follow Personal Protective Equipment (PPE) requirements outlined in this manual.
-  Always wear chemical-resistant gloves, such as nitrile, when working near print materials or with partially cured parts. It is recommended to wear approved goggles and protective clothing. Protective clothing includes, but is not limited to: closed-toed shoes, full-length pants, and splash-resistant lab coats or equivalents. 3D Systems recommends using 100% nitrile gloves; however, other chemical-resistant gloves will suffice. Do NOT use latex gloves, as they do not provide complete chemical protection.
- Wearing contact lenses when working with print materials is not recommended.
- Avoid breathing in vapors from print material. To avoid breathing in vapors: when opening the build chamber, allow a few seconds to pass before putting your face near the opening. No special facility and/or ventilation modifications should be required to operate the printer in a lab environment.
- Always wash skin thoroughly with a nonabrasive soap and COLD water after working with print materials. DO NOT USE HOT WATER OR SOLVENTS to wash hands, as these will stimulate your pores and result in absorption through the skin. Print material is sensitizing and can cause bad allergic reactions if absorbed through the skin. A person who becomes sensitized to print material should not work around that material in the future.
- If a small amount of resin gets on your clothing, remove the article of clothing as soon as possible (it might be a good idea to have a change of clothes on hand just in case). Have contaminated clothing dry cleaned. DO NOT wash in regular washing machine that drains into wastewater. If a particularly large amount of resin gets on your clothes, it is best to discard them according to all local, state, and federal regulations. Keep contaminated clothing away from food and drinks. Wash hands thoroughly after handling contaminated clothes, even if you wore protective clothing/gloves to handle them.
- Use extreme care when handling solvents that are used to remove excess print material from uncured parts. Some solvents are very flammable. See your solvent's SDS for more information.
- Keep all print materials away from heat, sparks, static discharge, and flame. Print material containers may rupture when exposed to extreme heat. We recommend storing your Figure 4 materials in a fire-resistant storage cabinet. Please refer to the SDS for a particular resin to view its flash point.
- High temperatures may cause a spontaneous polymerizing reaction, generating heat and pressure. Closed containers may rupture or explode during a runaway polymerization. Use a water spray or fog to reduce or direct vapors.
- Fire fighters should use a self-contained breathing apparatus and full protective clothing in the event of a resin fire.

- Do not leave uncured, or liquid, resins in an area where persons who are not knowledgeable about their handling or use may have access to them.
- Keep away from food and drinks.

WARNING: USE NATIONAL FIRE PROTECTION ASSOCIATION CLASS B EXTINGUISHERS SUCH AS CARBON DIOXIDE, DRY CHEMICAL, OR FOAM. A SPRAY OF WATER MIGHT ALSO BE EFFECTIVE. DO NOT USE A DIRECT JET OF WATER OR SMOTHERING TO EXTINGUISH BURNING RESIN OR SOLVENTS.

Print Material Characteristics

The photopolymers used in the print materials may be hazardous if handled improperly. Repeated skin contact with print materials may cause sensitization. Consult the manufacturer's Safety Data Sheet (SDS) for information on specific print materials. For further information on this and related topics, consult the 3D Systems Materials website.

WARNING: NEVER MIX DIFFERENT PRINT MATERIALS. DOING SO WILL RENDER BOTH MATERIALS INEFFECTIVE.

Figure 4 Material Storage

Print materials should be stored in the opaque, non-reactive containers in which they were provided, according to the guidelines given in the SDS included with the print material, and according to all applicable regulations (local, state, and federal). Protect print material from sunlight, ambient light, and moisture. Close the resin bottle after each use. Be sure your resin-storage area is dry, dark, and between 5°C-30°C (41°F-86°F). It is preferable to store the resin in a fireproof cabinet. Improperly stored resins may increase in viscosity, and may eventually result in a gelled, polymerized product in the storage container. Materials should be stored in conformance with applicable laws and regulations. The expiration date of the product is mentioned on the product label. If resin is past its expiration date, the product is no longer guaranteed in terms of treatment. 3D Systems is not responsible for losses incurred as the result of improper storage of print material.

Print Material Disposal

Do not dump print material down any drains. Dispose of print material according to the guidelines given in the SDS included with the print material and according to all applicable regulations (local, state, and federal). For more information on print-material disposal, please see the section Considerations for Resin in the **Chapter: Facility Requirements**.

Print-Material Spill Containment

A major print-material spill is unlikely during normal use of the Figure 4 Standalone Printer. However, there may be certain situations that require containment of a major resin spill. Your company has the responsibility to define what constitutes a major spill. Clean up spilled print material as quickly as possible, as material will cure under both natural and artificial lighting. Personnel who are involved in cleaning up major spills of print material should wear NIOSH/MSHA approved respirators designed for use with organic chemical vapors. In addition, each person should wear protective goggles, rubber boots, and 100% nitrile gloves to minimize exposure to print material, which can cause eye, skin, and respiratory irritation, as well as possible skin allergies and respiratory reactions.

WARNING: UNTRAINED PERSONNEL SHOULD BE EVACUATED FROM THE AREA.

WARNING: PRINT MATERIALS ARE FLAMMABLE. CARE SHOULD BE TAKEN DURING PRINT MATERIAL CONTAINMENT AND CLEANUP OPERATIONS.

A supply of dikes and control booms should be stocked so they are available to contain the affected area in the event of a major print-material spill. The spilled print material should then be absorbed on inert, absorbent material and placed into drums for transfer to an approved waste-disposal site. After absorbing all spilled material, clean the spill location with a nonabrasive cloth and IPA. After cleaning up the spill, individuals should wash thoroughly with soap and COLD water. Any clothing touched by resin should be dry cleaned before reuse. If resin has gotten onto your skin or clothes, avoid exposure to sunlight or other UV-light sources until skin and clothing have been cleaned of print material. Repeated or prolonged skin contact may cause sensitization. Vapor may be harmful.

Eliminate sources of ignition. Prevent entry into drains. Absorb spilled resin onto sand, earth or any other suitable adsorbent material. DO NOT absorb onto sawdust or other combustible materials. Resin spills or uncontrolled discharges into wastewater systems must be reported to the appropriate regulatory body. Do not discard resin into drains/surface waters/groundwater. Maximize ventilation after accidental release.

Shelf Life

Print materials are certified for use for 24 months from their date of manufacture. The expiration dates are marked on the material bottle labels. Resins should not be used past their expiration date. The printer will not accept the scan of a resin bottle that is expired.

In-Service Life

In-service life of the print material is defined as the useful life of the material after having been poured into the Figure 4 Standalone's resin tray. The in-service life of print material greatly varies depending on material type, usage and environmental conditions. If the material is exposed to temperatures outside of the normal operating limits, is exposed to UV light, is exposed to particulates or vapors in the air such as dust or fumes, or if contaminates are introduced such as partially cured platforms being placed back into the resin tray, this will shorten the material's in-service life. The types of patterns and builds performed also affect the in-service life of the material. With all this taken into consideration, the in-service life of the material is the same as its expiration date: two years. The material retains its usefulness until a buildup of viscosity or a change in reactivity prevents further processing in the Figure 4 Standalone Printer. All materials require some level of stirring or spinning to retain their properties. You must NOT mix resin from an old resin bottle with resin from a new resin bottle. These resins will be from different batches; and mixing them could render both ineffective. Follow the Instructions for Use of the specific material you are using for complete instructions on getting the most use out of it.

Contamination

Care should be taken when cleaning windows, panels, and other parts of the Figure 4 Standalone Printer. Cleaning products that contain ammonia should not be used because they can contaminate the material. Instead, use a small amount of isopropyl alcohol on a paper towel to clean up spills. Accidental contamination of resins may change the material’s performance characteristics to such an extent that acceptable parts can no longer be reliably created.

Polymerization

Polymerization may occur upon heating the resin bottle. Signs of polymerization of stored resin include container bulging, leaking, the emission of heat, or an unusual odor from the container. If you notice any of these traits, do not use the material and dispose of it according to all local, state, and federal regulations.

WARNING: SEALED CONTAINER MAY RUPTURE IF EXPLOSIVELY HOT. PLEASE SEE THE RESIN'S SDS FOR INFORMATION ON ITS FLASH POINT.

How to Treat and Dispose of Used ISA

http://infocenter.3dsystems.com/figure4standalone/user-guide/facility-requirements/considerations-material

How to Clean Up Resin Spills

http://infocenter.3dsystems.com/figure4standalone/user-guide/facility-requirements/considerations-material

Because Figure 4 materials are regulated, they are subject to special disposal requirements by your local, federal, or other regulatory agencies. Follow applicable disposal guidelines. Contact a local waste management company for recommendations on disposal requirements that affect your facility.

If your area requires regulated waste disposal, consult with and retain a waste-management company to periodically pick up regulated waste. Your local waste management company may recommend that you set up a drum, or other approved container, to dispose of liquid material, partially cured printed parts (also called "green" parts), and of any materials (such as paper towels or gloves) that may have come into contact with the uncured liquid material.

After final part curing in the LC-3DPrint Box, fully cured Figure 4 parts may be disposed of in regular trash receptacles.

How to Treat Accidents

Review the Figure 4 Standalone safety user guide online for the most current information on first aid and protective equipment:

http://infocenter.3dsystems.com/figure4standalone/user-guide/safety/first-aid-and-protective-equipment

The following paragraphs provide general first-aid procedures and recommendations for protective equipment to minimize the risks from print material exposure. If professional medical attention is necessary, take the Safety Data Sheet (SDS) for the exact print material involved to the attending physician.

Skin Contact

Figure 4 resin may cause sensitization by skin contact. It is irritating to the skin; repeated and/or prolonged contact may cause dermatitis. Wear 100% nitrile gloves and lab coats to avoid skin contact. Should print material come in contact with skin, wash thoroughly with soap and **COLD** water and immediately remove contaminated clothing and shoes. If skin is irritated, get medical attention. Dry-clean contaminated clothing. Discard contaminated shoes and leather products.

Eye Contact 

High vapor concentration may cause irritation. Safety goggles should be worn to prevent accidental splashes of print material into the eyes. If print material comes in contact with the eye, flush immediately with large amounts of **COLD** water for 15 minutes. Avoid sunlight, fluorescent light, and other ultraviolet light, and obtain immediate medical attention. Eye-wash facilities and a first-aid kit should be readily available and close to the print material.

Contact Lenses

If print material splashes into the eye when contact lenses are worn, flush the eye with water immediately. Verify that flushing has removed the contact lens from the eye. Protect eyes from light and obtain immediate medical attention. Discard contact lenses that come into contact with liquid print material.

Fume Inhalation

Inhaling fumes from Figure 4 resin is irritating to the respiratory system. High atmospheric concentrations may lead to irritation of the respiratory tract, dizziness, headache and anesthetic effects. Do not operate the Figure 4 Standalone Printer without its carbon filter in place. Normal operation of the printer with filter in place should not emit fumes. However, if a person should inhale printer fumes, bring the exposed person to fresh air. Perform CPR if required. If breathing is difficult, give oxygen and obtain immediate medical attention for the person.

Ingestion

Do not induce vomiting. Never induce vomiting or give anything by mouth if the victim is unconscious or having convulsions. Immediately rinse mouth and drink plenty of water. Get medical attention.

Emergency Shut Down

The Figure 4 Standalone Printer does NOT have an Emergency Stop button. The only way to stop printer operation during an emergency is by unplugging the power cord from the power inlet on the printer.

Instructions for Assessing the Final Project (File Prep Lab)

The assessment is based on each learner's 'priority' that was assigned to them, as well as a comparison to a benchmark of the same file.

We recommend giving learners unlimited opportunities to pass the File Prep Lab. If they do not pass, they can continue modifying their file until they pass. Record their highest score.

Orientation Considerations

Consider the priority assigned to the learner.

1. For speed, minimize height
2. For pack density, minimize XY surface area
3. For quality, identify A/B sides, B side down such that supports are on edges

Support Considerations

Consider the priority assigned to the learner. Also, take into consideration their orientation. If they did not orient properly, consider how this impacts their supports, and make a decision on how you wish to score the project.

1. Make sure all local minimums have a support, and have at least 3 in a triangle shape for stability
2. Even spacing of supports
3. Heavier density of supports on thicker areas

Delivery Instructions

Terminology

A few terms must be defined to help with design intent of this course. These terms are used to describe the tasks that are performed by learners

Term	Definition	Where Used
Exercise	A procedure or process that individual learners or small groups complete during class, either in software (on a laptop), or with the 3D printer	During a class or a lab
Assignment	A task learners must complete on their own, outside of class, prior to the next class session	After class with the intention of being completed prior to the next class

Delivery Instructions for Every Class Session

Use these instructions to guide you as you deliver the lessons. Additional tasks that are specific to a particular lesson are described within that lesson's plan (in this document).

Task / Activity	Expected Length	Required Tools	Directions
Prior to Class			
Review the lesson.	5 minutes	Instructor Guide	Read through the slides and instructor notes of the material that will be used in the lesson. If lecture is part of this lesson, turn your laptop on and open the PowerPoint file for this lesson. Make sure the projector is on and working. If an exercise is part of the lesson, make sure you have identified the files you need and have them readily available. Open 3D Sprint. Review the exercise. Review the file you start with, and the file you end up with.
Set up hardware.	15 minutes	Hardware, laptops, your laptop, printer, projector PowerPoint Instructor Guide Exercise files	Turn on each laptop in the classroom. Make sure the Figure 4 Standalone printer is on.
During Class			

Task / Activity	Expected Length	Required Tools	Directions
Review last lesson. Introduce this lesson.	5 minutes	Lecture	Remind learners what they did in the last lesson, and briefly tell them what they'll do in this lesson.
Deliver content.	Varies	Instructor Guide Projector PowerPoint Laptop	If lecture is a part of the lesson, open your instructor guide to the current lesson. Project the slides and use the instructor notes to deliver the lecture.
Demonstration	Varies	Videos Instructor Guide Projector Laptop/Software	
Manage learner exercises.	Varies	Instructor Guide Learner Guide Hardware	If exercises or demonstrations are a part of the lesson, open your instructor guide to the delivery instructions for any demonstrations and exercises.
Follow 3D Sprint exercise delivery plan.	NA	Files Learner Guide Instructor Guide	The process for each exercise that uses 3D Sprint will run as follows: 1. Instructors will tell the learners what they will show them. 2. Instructors will demo the tasks while learners (learner 1 at the laptop station, with learner 2 observing) perform the same tasks with the same file. 3. Learners (learner 2, then possibly learner 1 again) will then practice using 1-2 additional files. Each 'team' of learners (each laptop in the lab) will use a different file. 4. When they're finished with the exercise (using different files), each team will give a brief report to the class. Describe their part's geometries. Explain what they did (repair, orient, support). Describe any challenges they faced.
Summarize the lesson. Ask learners about any challenges they faced.	5 minutes	Lecture	Remind learners what they did in this lesson and what they'll do in the next lesson.
Review lesson by asking review questions.	5 minutes	Instructor Guide, Discussion	Ask each question listed at the end of the lesson, and have learners answer, out loud. Provide feedback.

Task / Activity	Expected Length	Required Tools	Directions
After Class			
Tend to the hardware.	10 minutes	Laptops, printer, projector, your laptop	Turn laptops off (if required). Keep printer on if needed. Be sure to put away other supplies.
Clean up the lab.	TBD	Supplies for	Perform any required clean up duties on the printer, in the post-processing area, or anywhere in the lab. Apply proper safety guidelines if you must clean up any spills or clean any machines.
Identify key topics or concepts that need to be repeated or addressed.	TBD	Instructor Guide	Mark down any topics that were not covered in this lesson that should have been, or additional topics that you need to cover based on the results of the lesson.

Course Components

	Component	Description	Required Components of Deliverable
1.	Content Slides	Used to deliver content	Each slide has a single purpose (fact, concept) and is supported by one or two images. Every slide must have a unique, intuitive title, with limited text on the slide. Each slide contains a full script for the instructor that includes everything they'll need to say for each slide.
2.	Instructor Guide (IG)	Walks the instructor through the entire delivery of the course and includes all questions and answers and exercise information. It is organized by lesson. Keep in mind that each lesson does not equal one class session (for example, 45 minutes). You need to determine how long it will take you to complete each lesson taking into consideration the use of the printer. Includes a section on classroom management and general instructions	The IG begins with general information: Class lesson list / outline, course objectives, how class will be run (its flow), number of learners and printers per class, explanation of limits on material and printer use, copyright information, safety information IG also includes tips and guidelines for conducting demonstrations. Each class lesson: Slides to use, what to say, structure of the Lesson, what to do and when, files to use, instructions for setting up, running, and concluding exercises plus all answers and hints/tips, exercise answers, questions and answers for the end of day, 3-5 questions per individual topic with answers and any explanations (plus identify exactly where the answer is found in the course content). This paragraph is bulleted, below. The following is identified for each lesson: • Instructions on what to do and when in order to deliver the lesson

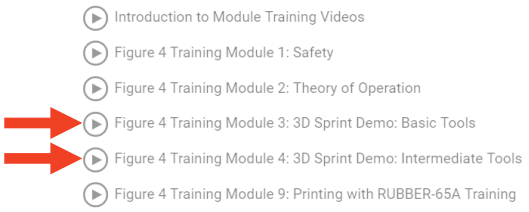
	Component	Description	Required Components of Deliverable
		for how the class will be delivered.	• files to use and when • instructions for setting up, running, and concluding exercises • all answers and hints/tips to the exercises and questions
3.	Learner Guide	Contains all slides, content, lists of additional resources, exercises, and questions used in the class. Organized by class lesson.	All exercises and instructions, slides, course outline, key content, images for the process, complete "job process", links to resources, all handouts, and all public videos that were shown
4.	.stl files	Learners will use these in their final project and throughout the course.	See the **Files** section in this document
5.	Several printed parts See the **Parts** section in this document	Use as examples, to explain certain concepts, and to demonstrate the results of an exercise	The parts should be more complex to demonstrate wall thickness, supports if possible, complex geometries, and maybe a mistake or fault in the print job.
6.	3D Sprint software	Base version	Each classroom laptop must have 3D Sprint installed on it prior to class beginning.
7.	Syllabus (this is part of the Learner Guide)	Course description with objectives, structure with topics	Objectives, lesson titles and objectives, basic learner tasks at each class/lesson, course structure (include the syllabus in the SG); it doesn't need to be separate
8.	Mid-Term Quiz	Safety and 'before project' quiz; workflow; prep	Mid-Term Quiz - Introduction to 3D Printing (Learners).docx/.pdf
9.	Final Quiz	All topics and project questions	Final Quiz - Introduction to 3D Printing (Learners).docx/.pdf

Lesson Exercises and Assignments

Exercises are completed in class under instructor supervision. Assignments may be assigned by the instructor throughout the course and are completed outside of class as homework. They are due at/during the next class session.

Lesson Title	In-Class Exercises	Homework Assignments
Lesson 1: Introduction to 3D Printing	None	• Research the 3D Printing Technician job. Bookmark an article or site to tell the class about. Report back, in the next lesson, with 1 or 2 important facts or concepts about the job • Read ***The history of 3d printer: from rapid prototyping to additive fabrication*** https://rebrand.ly/maintech • Read ***The Free Beginner's Guide*** on 3D printing: https://rebrand.ly/3Dbasics
Lesson 2: 3D Printing Technician Workflow	None	• Research the Figure 4 Standalone printer and write down a question you have about it. • Research the 3D Systems 3D Sprint software and write down a question you have about it.
Lesson 3: 3D Printing Technologies and Applications	None	• 3D Sprint https://support.3dsystems.com/s/article/3D-Sprint?language=en_US • Figure 4 Standalone 3D printer https://www.3dsystems.com/3d-printers/figure-4-standalone
Lesson 4: Material Properties	None	• Outside of class: Find an article that describes a 3D printing application – a way 3D printing was used. • Download and read (and study!) the Figure 4 PRO-BLK 10 material data sheet and safety data sheet. It's important to be able to find this information, and to read it before working with the printer. • Read the ASTM standards document (provided for you in this Learner Guide).

LESSON TITLE	IN-CLASS EXERCISES	HOMEWORK ASSIGNMENTS
Lesson 5: 3D Systems Figure 4 Standalone Printer	None	• Locate a Figure 4 use case online. • Download a Figure 4 brochure from 3D Systems online.
Lesson 6: Designing for 3D Printing	1. Locate the 3D Sprint software and open it. Take a moment to look around. Press F1 to open the help feature and see if you can find information on support structures. Read that brief section. 2. Take a look at the Figure 4 printer. Without pushing any buttons, examine the outside. Locate the build platform. Identify post-processing tools, the cleaning station, where to dispose of waste, lab coats and safety glasses.	None

Lesson 7: 3D Sprint Demonstration	• Follow along during class in 3D Sprint using the same file as the instructor. Groups take turns working in 3D Sprint.
	  • Import a file
	  • Describe the CAD file in 3D Sprint
	  • Manipulate the CAD file in 3D Sprint
	  • Navigate through 3D Sprint's Prepare, Print, and Queue tabs
	  • Identify possible issues with a part/file that you imported
	• Locate the various tools shown in this lesson
		• Watch these two videos on you tube to prepare for the next few lessons. http://3dsyste.ms/3ds7
		 

Lesson Title	In-Class Exercises	Homework Assignments
Lesson 8: Workflow Step 1: Select/Confirm the Material and Printer	• Select/Confirm the Material and Printer	• Search for the 3D Systems Figure 4 Material Selection Guide • Search for the 3D Systems Material Buyer's Guide • Figure 4 Tutorial Module #2 - Theory of Operation (listed in the image above, in Lesson 7) https://bit.ly/38d1Czh • Figure 4 Isotropic Properties https://bit.ly/2CXyCjt
Lesson 9: Workflow Step 2: Import, Examine, and Repair the Part File	• Import, Examine, and Repair a Part File	None
Lesson 10: Workflow Step 3: Orient the Part and Create Support Structures	• Orient the Part and Create Support Structures	• Read "*How does part orientation affect* your 3D printed parts?" by Sculpteo https://bit.ly/2ZrAvfB • Read "How does part orientation affect a 3D print?" by 3D Hubs https://bit.ly/2AiLrnn • Browse the 3D Sprint Help site https://rebrand.ly/1345yl3 • Review today's videos and watch additional videos on Figure 4 Standalone https://rebrand.ly/umkv5cw
Lesson 11: Workflow Step 4: Print the Part	• Make sure your file is ready to print. All teams should be ready to print before the end of this class session. However, only the instructor will print.	• Review your Learner Guide, notes, and handouts to prepare for the quiz. Quiz has 20 questions. The quiz contains questions on these topics: o Safety o Figure 4 Standalone o 3D Sprint o Workflow and processes
Lesson 12: Workflow Step 5: Post-process the Part	Mid-Term Quiz	None
Lesson 13: Workflow Step 6: Inspect the Part	Inspect Several Parts. Report back to class on findings.	None
Lesson 14: Secondary Processes	None	None
Lesson 15: Maintaining and Troubleshooting Figure 4 Standalone	None	None

LESSON TITLE	IN-CLASS EXERCISES	HOMEWORK ASSIGNMENTS
Lesson 16: Course Summary	None	• Study for the Final Quiz – The Final Quiz is delivered during the last class, after labs. The Quiz has 20 questions. Learners are quizzed on these topics: ○ AM technologies, processes, applications, industries ○ Material properties, reading material data sheets ○ Safety ○ Figure 4 Standalone and maintenance ○ 3D Sprint, geometries, and design terminology ○ Part orientation and supporting structures ○ Workflow ○ Processes
Lesson 17: File Prep Lab	**FILE PREP LAB** 1. Perform Steps 1-3 2. Submit to Instructor • Instructor approval	• Study for the Final Quiz
Lesson 18: Print Lab	**PRINT LAB** 1. Send your part to the printer. Make sure the print job is in the queue. 2. Watch your part print for several minutes to make sure it starts correctly. 3. Inspect your part. 4. Complete and submit the **Template – Quality Report.xlsx** form after you complete your part inspection. 5. Post-process your part. Practice proper safety protocols. 6. Show your part to your instructor for grading and review. 7. Perform appropriate maintenance and cleaning on the printer, part, and lab area. Discuss what needs to be done with your instructor first, before you start.	• Prepare your project report • Study for the Final Quiz
Lesson 19: Project Reports and Final Quiz	• Project Reports • Final Quiz	• Complete the online Course Evaluation.

LESSON DEMONSTRATIONS

Demonstrations are completed in class as part of, or immediately following lectures / PowerPoint presentations.

LESSON TITLE	DEMONSTRATION GOALS
Lesson 1: Introduction to 3D Printing	Not Applicable
Lesson 2: 3D Printing Technician Workflow	Not Applicable
Lesson 3: 3D Printing Technologies and Applications	Not Applicable
Lesson 4: Material Properties	Not Applicable
Lesson 5: 3D Systems Figure 4 Standalone Printer	Not Applicable
Lesson 6: Designing for 3D Printing	Not Applicable
Lesson 7: 3D Sprint Demonstration	• Import a CAD file into 3D Sprint. • Describe the CAD file in 3D Sprint. • Manipulate the CAD file in 3D Sprint. • Identify possible issues with the part/file. • Repair issues with the part file. • Navigate through 3D Sprint's Prepare, Print, and Queue tabs. • Locate the various tools shown in this lesson.
Lesson 8: Workflow Step 1: Select/Confirm the Material and Printer	• Import a CAD file into 3D Sprint. • Read the part order form and analyze the part request. • Prioritize part requirements. • Use the various material selection guides/tools to identify the correct technology, printer, and material.
Lesson 9: Workflow Step 2: Import, Examine, and Repair the Part File	• Import a CAD file into 3D Sprint. • Describe the CAD file in 3D Sprint. • Assess the part for errors. • Repair issues with the part file.
Lesson 10: Workflow Step 3: Orient the Part and Create Support Structures	• Orient a part file. • Add support structures for a part file.
Lesson 11: Workflow Step 4: Print the Part	• Review material and safety data sheets in order to print the part • Print the part • Watch the beginning to make sure it adheres to the platform and the print job begins well

LESSON TITLE	DEMONSTRATION GOALS
Lesson 12: Workflow Step 5: Post-process the Part	• Remove the part from the platform • Clean the part and platform • Remove the support structures • Return the Wash and Rinse tubs and cleaning area to their initial state (i.e. clean up the area) • Cure the part
Lesson 13: Workflow Step 6: Inspect the Part	• Visually inspect the part • Use a caliper to take measurements • Compare the measurements to the part requirements form and check tolerances
Lesson 14: Secondary Processes	Not Applicable
Lesson 15: Maintaining and Troubleshooting Figure 4 Standalone	Not Applicable
Lesson 16: Course Summary	Not Applicable
Lesson 17: File Prep Lab	Not Applicable
Lesson 18: Print Lab	Not Applicable
Lesson 19: Project Reports and Final Quiz	Not Applicable

QUIZZES AND SCORING

The Mid-Term Quiz (answer key) is located within Lesson 12 in this Instructor Guide. The file to be printed for learners is Mid-Term Quiz - Introduction to 3D Printing (Learners).docx or .pdf.

The Final Quiz (answer key) is located within Lesson 19 in this Instructor Guide. The file to be printed for learners is Final Quiz - Introduction to 3D Printing (Learners).docx or .pdf.

SCORING AND LEARNER GRADES

Mid-term quiz	20%	/20 points	Required minimum score of 16 to participate in the Print lab.
File prep lab	20%	/20 points	Required minimum score of 16 to participate in the Print lab.
Print lab	20%	/20 points	
Final Quiz	20%	/20 points	
Project Report	20%	/20 points	

Part Files for Class

Make sure you have all part files needed to demonstrate principles and content, conduct the exercises, and hand out for the final project.

Remember to assign a specific priority to each learner for their final project.

Parts to Print for Class

Print several parts before class to demonstrate the types of parts that can be printed, common mistakes, orientation issues, and support structures.

A list of all parts provided with the course is titled **Introduction to 3D Printing - Course Files.xlsx**. Use this file to identify parts to print and to create 'bad parts' that illustrate printing errors.

At a minimum, you should print parts that illustrate these issues:

- Stair stepping
- Warpage
- Delamination

Also print these 'good quality' parts that illustrate these concepts:

- A good part, fully cured
- Snap fit or other assembly part
- 2-3 Jewelry pieces

Introduction to 3D Printing – Lesson Plans

Lesson 1: Introduction to 3D Printing

The first lesson introduces learners to the field of 3D printing and prepares them to succeed in this course.

Goals

1. Become familiar with the classroom, structure of the class, Figure 4 Standalone printer, 3D Sprint software, syllabus, and learner guide.
2. Identify the course goal – become a Figure 4 printing technician.
3. Describe the three types of manufacturing (formative, additive, and subtractive).
4. Explain the benefits of 3D printing.
5. Identify the industries and applications that use 3D printing.
6. Research the 3D Printing Technician job. Bookmark an article or site to tell the class about.

Lesson Objectives

- Identify the course goal.
- Describe three primary types of manufacturing.
- Explain the benefits of 3D printing.
- Identify the industries and applications that use 3D printing.

Topics

Classroom

- Learner Guide – make sure each learner has a SG
- Physical classroom, quick tour (learners stay seated)
- Course structure and learner guide
    - 1 project at the end of class, but several exercises along the way
    - Learners or Teams will always report their findings at the end
- Syllabus, course objectives, course goal is within the Learner Guide
- Group learners at each laptop (with a mouse); determine order for printing (same order for all Workflow Steps)

Overview of 3D Printing

- Three types of manufacturing
    - Comparing cost curve of different types of manufacturing

- What is 3D printing?
    - Interchangeably used with AM
    - Significance of the part
- Evolution of manufacturing leading to 3D printing
    - Explain the origin of the term “Rapid Prototyping”
    - List industries that adopted Rapid Prototyping
    - The switch from “Rapid Prototyping” to “3D Printing” to “Additive Manufacturing”
- What is the cost?
- AM defined and its benefits
    - Freedom of design
    - Reduction of assembly; Reduce number of printed parts; print as a single part

Applications

- Concept of applications vs. industries (horizontals vs verticals)
- Design cycle – and parts produced along the way; why are they important?
    - Where are printers used; which printers
    - Cost savings/cutting (errors, with prototyping, for example)
    - Prototyping
    - Production of patterns for casting (example, jewelry)

Exercises

None

Assignments

- Research the 3D Printing Technician job. Bookmark an article or site to tell the class about. Report back, in the next lesson, with 1 or 2 important facts or concepts about the job
- Read ***The history of 3d printer: from rapid prototyping to additive fabrication*** https://rebrand.ly/maintech
- Read ***The Free Beginner’s Guide*** on 3D printing: https://rebrand.ly/3Dbasics

Additional Resources: On Your Own

Encourage learners to find or explore these additional resources on their own time.

- The 3D Printing Handbook: Technologies, design, and applications by 3D Hubs (Ben Redwood, Filemon Schoffer, and Brian Garret)
- 3D Printing Technician Job Description Example - Voodoo-Mfg-Job-Description-3D-Printing-Technician.pdf

LESSON 2: 3D PRINTING TECHNICIAN WORKFLOW

Becoming a 3D Printing Technician is the purpose of this course. The position is introduced in this lesson. More information about the structure of the team/lab work is also provided.

GOALS

1. Explain the entire process of fulfilling a part request using the 3D Systems Figure 4 Standalone printer and material.
    a. Use a diagram to represent the process
2. Establish teams and working stations – learners will use assigned laptops (with mouse) and stay in assigned teams throughout the class.
3. Report back to the class. Share your article, summarize the information you read, or share something exciting that you learned about being a 3D Printing Technician.
4. Introduce the Figure 4 Standalone and 3D Sprint as the main tools and focus of this class.

LESSON OBJECTIVES

- Explain the entire process of fulfilling a part request using the 3D Systems Figure 4 Standalone printer and material.
- Introduce the Figure 4 Standalone and 3D Sprint as the main tools and focus of this class.

TOPICS

3D PRINTING PROCESS

- Process diagram and process, high level
    - Design/import stl file
    - Repair
    - Place/orient
    - Build support structures
    - Print
    - Mid-build inspection (while still building, halfway through build)
    - Remove print
    - Post-process
    - Inspect
    - Secondary processes
- People/roles involved
    - Applications Engineer (helps customer pick material, checks model, technical details)
    - Print lead (manages queue, prioritizing orders)
    - Design Engineer
    - Manufacturing Engineer
    - Inspector, quality control, measure parts, meet specs, right part for specific order

Technician Workflow

- 3D part process (high level, highlighting 3D Sprint and Figure 4 printer)
- Process diagram

Printer Technician Workflow

Step 1: Select/Confirm the Material and Printer

Step 2: Import, Examine, and Repair the Part File

Step 3: Orient the Part and Create Support Structures

Step 4: Print the Part

Step 5: Post-Processing

Step 6: Inspect the Part

Step 7: Ship the Part

Being a 3D Printing Technician

- A Day in the Life of a 3D Printing Technician job responsibilities
  - Check in with lead
  - Get information on jobs in progress
  - Process jobs
  - Maintain the printer
  - Make note of supplies running low; inventory
  - Hand off jobs in progress to next shift
- Key tasks
- Learners report on being a 3D Printing Technician

Class Exercises and Activities

- The course follows the process
- General structure of the course - Instructor will lecture (tell them what he'll show them, then demo while learners follow along, then learners will do it on their own, then report on how it went, and class will end with question and answer review session

Introduction to Figure 4 Standalone and 3D Sprint

- Figure 4 Introduction –we'll use this in this course; what it is; basic info
- 3D Sprint Introduction –we'll use this in this course, what it is, basic info

Exercises

None

Assignments

- Research the Figure 4 Standalone printer and write down a question you have about it.
- Research the 3D Systems 3D Sprint software and write down a question you have about it.

Additional Resources: On Your Own

Encourage learners to find or explore these additional resources on their own time.

- The 3D Printing Handbook: Technologies, design, and applications by 3D Hubs (Ben Redwood, Filemon Schoffer, and Brian Garret)
- https://www.3dsystems.com/software/3d-sprint

Lesson 3: 3D Printing Technologies and Applications

The objective of this lesson is to introduce the various 3D printing technologies prevailing today. It's important to explain that (1) one technology can't solve all 3D printing challenges, and (2) one 3D printing challenge can be solved by many technologies.

Goals

- Identify key/basic ASTM standards for additive manufacturing.
- Describe the different additive manufacturing technologies and their unique benefits.
- Distinguish between 3D printing technologies in terms of process, materials, benefits, post-processing, and applications. (pick a term for objectives)
- Identify the industries in which each 3D printing technology is used the most.
- Explain the materials that can be used for each technology, including support material.

Lesson Objectives

- Identify key/basic ASTM standards and terminology for additive manufacturing.
- Distinguish between 3D printing technologies in terms of process, materials, benefits, post-processing, and applications.
- Identify the industries in which each 3D printing technology is used the most.

Topics

Standards

- ISO/ASTM 52900; chart of technologies
- Frequently used terms for…; use the chart for technologies

3D Printing Technologies and Their Unique Benefits

- Material extrusion / FDM
- Vat polymerization (DLP, SLA)
- Powder bed fusion (polymers) (SLS)
- Powder bed fusion (metals) (DMP)
- Material jetting (MJP)
- Binder jetting (CJP)
- Direct energy deposition (possibly remove)

The following information is covered for each technology, above:

- Brief history
- Current products
- Printer characteristics

- Dimensional accuracy
- Materials; class of materials (not a deep dive into exact materials)
- Post-processing
- Benefits and limitations
- Common applications (for this technology)

Demonstration

- Review material and safety data sheets in order to print the part
- Print the part
- Watch the beginning to make sure it adheres to the platform and the print job begins well

Exercises

None

Assignments

None

LESSON 4: MATERIAL PROPERTIES

This lesson explains the properties that are used to describe materials, what the properties mean, and how to read a data sheet.

GOALS

- Describe the different types of materials.
- Define material properties.
- Locate 3D Systems material data sheets.
- Locate Figure 4 Standalone material data sheets.
- Identify the key components of a 3D Systems material data sheets and material safety data sheets.

OBJECTIVES

- Identify the different types of materials.
- Describe key material properties.
- Identify the key components of a 3D Systems material data sheet.
- Identify various types of materials for each technology.

TOPICS

MATERIALS

- Types of materials
    - Polymers
    - Thermoplastics
    - Thermosets
    - Metal
    - Other
- Material properties, definition, what the range means, use images, some examples
    - Introductory slide – there's no good or bad value - (answer question, 'what's a good value for each?' – explain it depends on end use)
    - Properties
        - HDT
        - Flexural Modulus
        - Flexural Strength
        - Impact Strength
        - Tensile Modulus
        - Tensile Strength

        - Viscosity, low value is water-like, high value is thick like molasses (teach what the range 'means, slider image)
        - Elongation at Break
- Watch video to show how to find material data sheets
- How to read a material property data sheet
    - Property values
    - Benefits
    - Applications

Applications

Printer Use Cases (Other Printers ok to include) (Focus on why these printers were chosen, and why these materials were chosen)

- Key point: one technology can't solve all 3D printing challenges
- Key point: one 3D printing challenge can be solved by many technologies.
- In which industry/application each printer technology is used
    - Jewelry
        - Printing wax patterns on MJP
    - Medical
        - SLS, PA
    - Investment Casting
        - QuickCast on SLA
    - Production
        - Replacing vacuum casting and injection molding by printing Pro-BLK 10 on Figure 4.

Exercises

None

Assignments

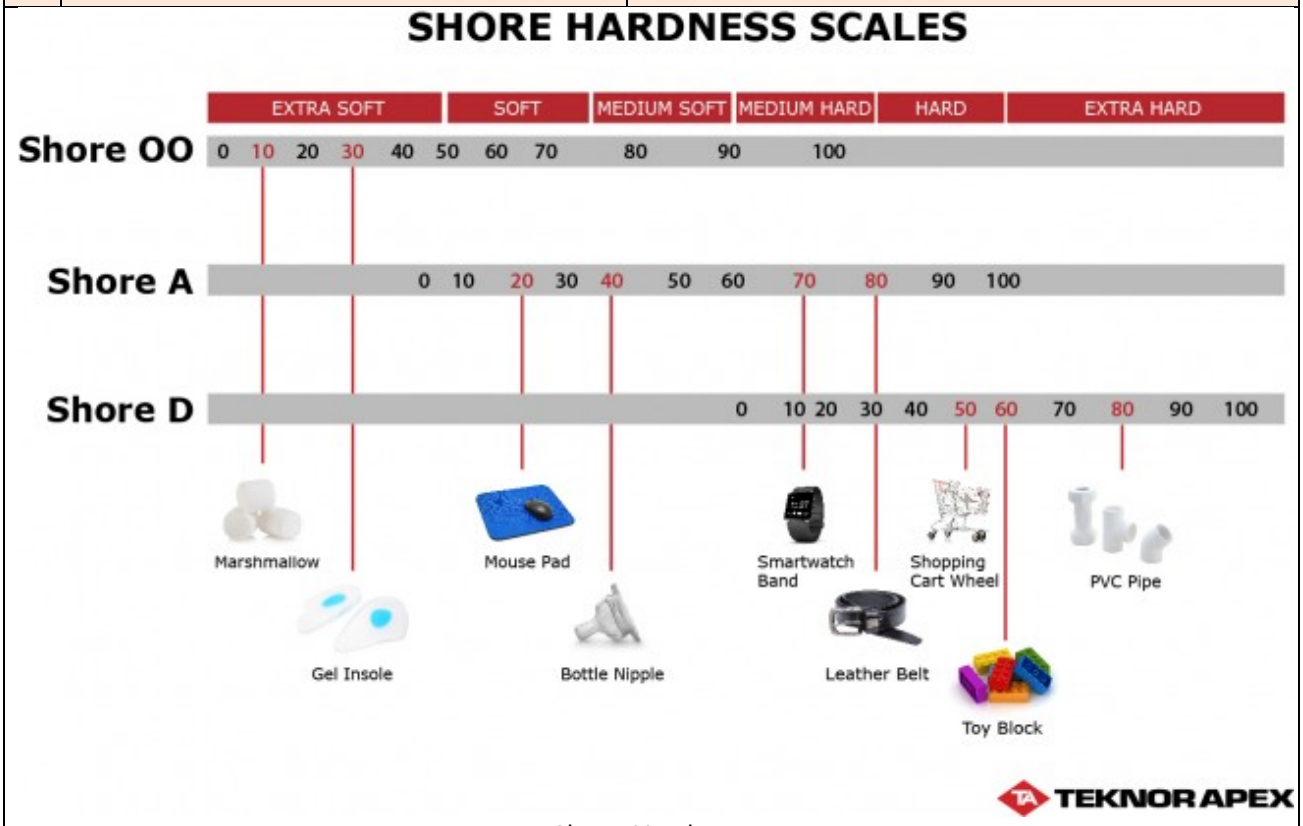
- Outside of class: Find an article that describes a 3D printing application – a way 3D printing was used.
- Download and read (and study!) the Figure 4 PRO-BLK 10 material data sheet and safety data sheet. It's important to be able to find this information, and to read it before working with the printer.

    a. The learners should read the material and safety data sheets for whichever material you're using in the lab. If the material is different from PRO-BLK 10, be sure to emphasize which material data and safety sheets they should read.
- Read the ASTM standards document.

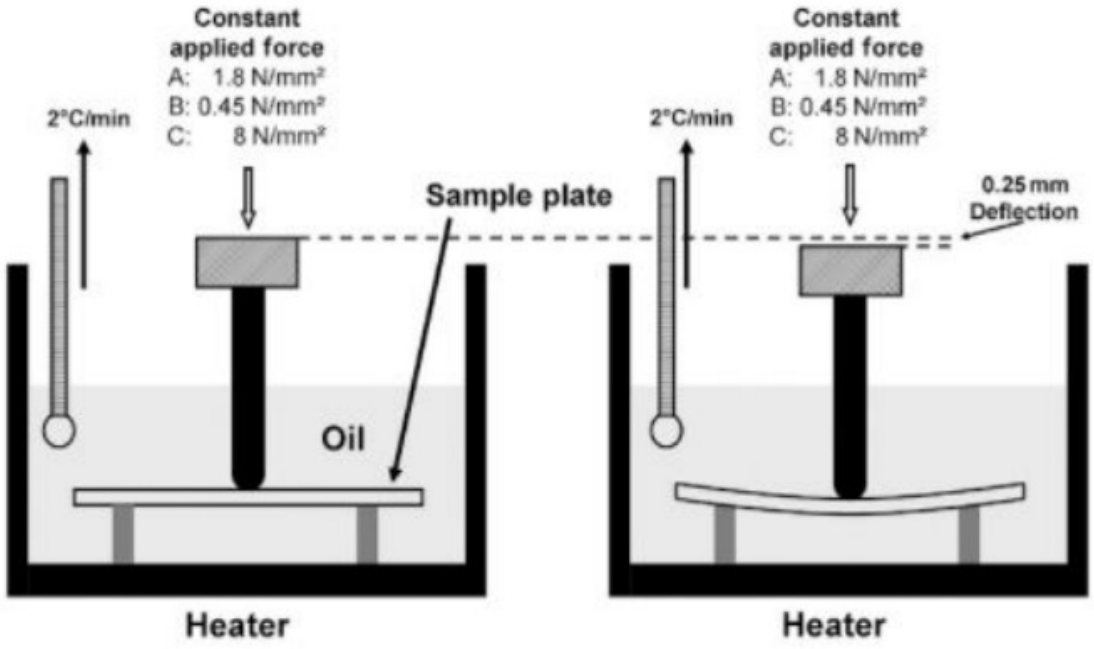
Material Property Information, Terminology, and Values

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
1.	**ABS** Acrylonitrile Butadiene Styrene. Common plastic used in manufacturing. Petroleum-based, properties include impact resistance, toughness, and heat resistance. Generally useful from ~20-80°C (~4-176°F). ABS is damaged by sunlight.	Two major categories for ABS include extrusion and injection molding, with high and medium impact resistance. FDM commonly uses ABS. End-users may request ABS plastic due to it's familiarity. Determine what mechanical expectations are needed so that appropriate recommendations can be made
2.	**ABS-like** Having mechanical properties similar to ABS. Many printable plastics have similar properties.	Many non-extrusion polymers have mechanical properties similar to ABS. Determine what mechanical expectations are needed so that appropriate recommendations can be made
3.	**Article** Manufacturing parlance: parts	Know the language of the customer: first-article success refers to the first part being produced by whichever process is in use as being "viable"
4.	**Assemblies** 2 or more parts that are designed and intended to combine, connect, or interact with each other to perform their purpose	Printed parts from every technology are often used as the visual and/or physical prototypes, or functional proxies, or usable parts in artistic, functional, or final manufactured assemblies.
5.	**Assemblies, Functional** Assembled parts that can endure a physical interaction as a unified function	Toothed gears, interlocking panels, hinges, etc.
6.	**Assemblies, Threaded** Assembled parts that connect to each other with screw-threads, similar to a nut and bolt.	Some 3d printers and materials are able to build parts with the accuracy and surface detail necessary to be used as threaded assemblies. Most rigid mjp, sla, and fig4 plastics are suitable,
7.	**ASTM** ASTM International, known as American Society for Testing and Materials, is an international standards organization that develops and publishes technical standards for a wide range of materials, products, systems, and services	Printable materials are tested to perform at specific ASTM standards. Customers evaluate ASTM results as a way to compare various materials, and determine if a material is suitable for their application.
8.	**Autoclave** A method of sterilization. An Autoclave is a machine that can use combinations of pressure, chemicals, heat, steam and light to sterilize objects for medical use	Some 3D printed plastics and metals are able to go through an Autoclave process for medical and dental use. One or more material from each plastics and metal printer family produces parts that can be Autoclaved.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
9.	**Biocompatibility** Suitability to be used in contact with skin and tissue. There are varying degrees of biocompatibility described by ISO standards, that are dependent upon the intended duration of contact, and whether that contact is external or implanted.	Each technology can produce parts with varying degrees of biocompatibility. Some parts just need to be sterilized so they can be present as a visual model in an operating environment, some parts just need to touch the skin or mouth as a temporary guide, while some parts need to be implanted inside the body for permanent integration with tissue. Customers are responsible for determining the suitability of a specific material for their biocompatibility needs.
10.	**Burnout** A step in the investment casting process when a sacrificial pattern is incinerated from the mold	Some 3D printed plastics and wax can be used as sacrificial patterns. These patterns get "burned-out" of the investment leaving a cavity that becomes a mold which gets filled with liquid metal to create a final part
11.	**CNC machine** Computer Numerical Control. CNC or machining has become shorthand for the act of programming a machine to remove material in a subtractive manner to achieve a desired part. CNC is subtractive, the opposite process of 3D printing, which is additive.	CNC requires software to program the behavior of the various brands of machines and the assorted tools that they use. GibbsCAM is CNC software that consolidates the controlling of any brand of machines performing these actions.
12.	**Composite Materials** A composite material is a one made from two or more base materials with different physical properties, that when combined, produce a material with characteristics different from the individual components.	CeraMAX is a true composite SLA resin, white MJP multi material printing may be referred to as a composite even though it is a blended plastic.
13.	**Cure/Curing** the act of using catalyzing agent(s) (heat, light, chemicals) to activate a substance to solidify.	Curing is necessary to make a liquid 3d printed plastic safe to handle as well as to achieve mechanical properties.
14.	**Cytotoxicity** The quality of being toxic to cells	Biocompatible printed plastics are chosen for their lack of cytotoxicity
15.	**Durometer** The international standard for measuring the hardness.	Hardness, measured most commonly on a Shore A or D scale, is a material's resistance to surface penetration. Think of this property as how much force it takes to create a ‘dent’ in the material.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
	 Shore Hardness	
16.	**Elastomers** A polymer that displays rubber-like elasticity, generally low Young's modulus and high failure strain compared with other plastics. The term is used to imply "rubber-like". Relatively compliant and deformable.	Primary uses are for seals and molded flexible parts. Rubber-like solids with elastic properties are called elastomers.
17.	**g/cm3, or lb./in3** A measurement of density. Grams per cubic centimeter (metric), or pounds per cubic inch (imperial).	The density of materials are measured by comparing mass and volume The density of water is so close to 1 g/cm3 that is widely used a constant for comparison. A density <1 will float; >1 will sink.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
18.	**HDT** Heat Deflection Temperature, or Heat Distortion Temperature. The point at which a material ceases to keep its shape	HDT is used to describe the temperature endurance of 3D printed materials. @66PSI and @264PSI are the low and high pressure testing standards commonly used. HDT is often a misused property. It is the temperature at which a material deforms under a very specific load, either 66 psi or 264 psi. The test specimen is submerged in oil, supported on both ends. A constant force is applied in the middle. The oil is increased in temperature at a rate of 2°C per minute. When the specimen deflects 0.25mm, the temperature of the oil is recorded. It is that temperature that is said to be the materials 'HDT' for the specific applied force. HDT CANNOT measure the materials ability to withstand heat over the long-run. It is best used to compare materials, not to choose a particular material. Ultimately, end-use testing is the best way to ensure a particular design / material / end-use property combination will meet expectations.



HDT

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
19.	**Investment casting** the surrounding of a sacrificial pattern in a temporary material. The pattern is melted or incinerated from the investment, and then a liquid metal is placed into the resulting cavity. The investment is then broken from the solidified metal once cooled.	Some 3D printed plastics and wax can be used as sacrificial patterns in the investment casting process
20.	**ISO** International Organization for Standardization. A global network of the standards bodies in 160+ countries. A consensus of testing methods to evaluate the performance of materials	10993 is a common ISO standard for material biocompatibility with various levels to indicate expectations of contact. Review the ISO.org website for explanations of their various standards.
21.	**Izod Testing (notched vs unnotched)** Izod is an ASTM standard method of testing to determine the impact strength of materials. A pivoting arm is raised to a specific height and then released. The arm swings down hitting a notched sample, breaking the specimen. The device measures the amount of force required to fracture (or not) the specimen.	The standard for Izod testing is performed on notched samples to designate a predictable fail-point. An unnotched sample has no "notch" to create a fail point, thereby resulting is a stronger part. All plastics can be forced to eventually fail by increasing force applied, however the Izod testing machines have mechanical limits based on their size.
22.	**J/m, or Ft-lbs./in** Joules per meter (metric), or foot pounds force per inch (imperial). A measurement of force being applied.	Impact strength of 3D printed materials are evaluated with this metric. This refers to the intensity it can withstand being struck without deforming or breaking.
23.	**kN/m, or lbf/in** kilonewtons meter (metric), or pounds feet (imperial). The units to measure force being applied	Tear Strength of materials are measured in kN/m or lbf/in
24.	**KSI** Kilopound (Pound Force) per square inch. A unit of pressure. The megapound per square inch (Mpsi) is another multiple equal to a million psi.	The tensile modulus and flexural modulus of printed materials are described by the KSI they can endure. These measurements describe a material's ability to bend/stretch without deforming.
25.	**Malleable** Able to be pressed out of shape without breaking or cracking. Pliable.	

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
26.	**Micron** One thousandth of a millimeter. Abbreviated as µm	3D printers measure the fineness of their produced parts and their ability to print in microns. The smaller the micron layer fineness, the greater the potential detail in the part. Finer micron printing layers generally increases printing time within a specific print technology.
27.	**MPa** MegaPascal (MPa): 1 MegaPascal = 1 million Pascal's. The Pascal (symbol Pa) is a unit of pressure. It is equivalent to one Newton per square meter.	The tensile strength of 3D printable materials are measured in MPa and PSI
28.	**PCA** Post-curing apparatus. A machine used to cure the printed parts made from uv-curable liquid resins using lamps which emit a wavelength of light that causes the curing reaction to be initiated.	SLA and FIG4 prints require post curing for parts to be handled, and to achieve published mechanical properties
29.	**Polypropylene** Polypropylene. A thermoplastic polymer used in a wide variety of applications. Properties are similar to polyethylene, but slightly harder and more heat resistant. In it's natural state, it is white, mechanically rugged and has a high chemical resistance. The second-most widely produced plastic, often used in packaging, textiles & yarn (carpet), medical, consumer products. When the polymer is reinforced with fiber glass, it is found in structural parts in automotive. When the polymer is reinforced with talc and impact modifiers, it is made into automotive bumper fascias. It is also used extensively as molded-in-color interior automotive trim.	End users may ask for 3D printed materials that have the mechanical properties of PP.
30.	**Post-processing** Post-processing is an essential stage of additive manufacturing. It's the last step in the manufacturing process, where parts receive finishing touches such as smoothing and painting.	Post-processing improves the quality of parts and ensures that they meet their design specifications. The finishing process can enhance a part's surface characteristics, geometric accuracy, aesthetics, mechanical properties, and more. For samples and prototypes, this can mean the difference between a sale or a loss. For production parts, finishing creates a part that is ready to use.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
31.	**PP / Polypropylene-like** A non-polypropylene that has PP flexural modulus mechanical properties.	SLA Accura® 25 and Accura® 55 are good examples of materials often used to create prototypes that 'feel' as flexible as PP.
32.	**Ppm/ degrees F CTE** Parts Per Million (at degrees F/C), or Coefficient of Thermal Expansion	A measurement of how much a material expands when it is heated.
33.	**Print speed** the rate at which a 3D printer deposits build-layers to create a part. Print speed is measured in vertical mm/hr.	3D print speed does not take into account time needed to cure and post-process printed parts which can add significant time. Customers effectively care about time to parts-in-hand, which takes into account all steps in the process to generate a finished part.
34.	**PSI** Pounds per Square Inch. A measurement of pressure	The tensile strength of 3D printable materials are measured in Map and PSI
35.	**Resolution** Horizontal resolution (XY resolution) is the smallest movement the printer can make within a layer on the X and the Y axis. The lower the value, the higher the details the printer produces. Vertical resolution (or layer thickness or layer height) is the minimal thickness of a layer that the printer produces in one pass. The smaller the layer thickness, the smoother the printed surface will be. However, the printing process will take longer for finer layers as the printer has to produce more layers.	There are three resolution dimensions to consider: two planar dimensions (X and Y) and the Z dimension. The planar and Z dimensions are generally controlled via different mechanisms, their resolutions are going to be different. Z resolution in microns is often the only advertised datapoint. Resolution is different from minimum feature size.
36.	**RTV** Room Temperature Vulcanization. RTV materials begin as a liquid, then get poured into a mold or onto a form to attain a desired shape, where they will then cure into a solid (or "vulcanize") at room temperature.	Hand-made silicones and rubber parts are generally more soft than rigid and referred to as RTV materials. Several high temp rigid printed materials can be used as master pattern mold forms which RTV silicone is poured "around". The cured RTV part is then peeled away. 3D printed parts can also be used as a hollow sacrificial mold form to enable the use of RTV materials to be poured "inside". The part is then shattered to reveal cured parts. A few specialized materials are ideal for this: MJP M2S HT90, FIG4 EGGSHELL AMB, SLA ACCURA SAPPHIRE
37.	**Sacrificial tooling** Single-use or low-volume use tooling that gets destroyed by the act of using it	Eggshell molds are an example of single-use sacrificial tooling

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
38.	**Sensitization** The state of skin/tissue developing adverse allergic reactions to chemicals and/or foreign substances.	Many chemicals including uncured 3d printing resins are sensitizing agents. Resin sensitization can include rash, skin breakage and bleeding. Liquid resin and uncured plastic parts should never be handled with bare skin. Severe allergic reactions can occur. Sensitization is sudden and
39.	**Short-run production** Traditional manufacturing requires a minimum number of parts to be financially justifiable. "Short-runs" refer to the creation of fewer parts than what is needed to break-even on the time and cost of their own creation.	3D printed parts are often used to satisfy the demand for low quantities of parts. "Short" quantities vary by industry, part-size and manufacturing method. Generally, runs of 1-100
40.	**Silicone molding** The creation of silicone parts using molds and forms	Eggshell molding is a process of creating sacrificial 3D printed parts to produce custom silicone parts
41.	**Soft Tooling (vs. Hard Tooling)** Mold tooling typically made with types of silicone, plastics, and other non-metals. In bigger industirial use, Aluminum is considered soft tooling, where Steel is considered hard tooling.	Cast urethanes generally use soft tools, typically made with a type of silicone mold. The mold is created via a master pattern. Master patterns for cast urethanes can be created with CNC machining or 3D Printing. The cost for soft tooling is significantly lower making it a resource for planners still testing product design, for one-off products, or for testing market and consumer response to a new product. In comparison, hard tools for injection molding, usually made of metal, and are subjected to a lot of stress and heat during the injection process. They experience runs of thousands of parts per day. The care that goes into a metal tool involves intense machine programming and finishing which costs thousands of dollars, and takes several weeks to create.
42.	**Thermal post-cure** The process of applying heat to a part for a specific amount of time to increase the temperature resistance (HDT) of a material.	This process can change the clarity of plastics, as well as the HDT of the parts. FIG4 HI TEMP 300-AMB is an example of a printable resin that can achieve extreme HDT of over 300°C with a thermal post-cure
43.	**Thermal resistance / HDT** Heat Deflection Temperature. The temperature a material can endure. A description of thermal resistance.	High HDT plastics are often more brittle, but able to endure high temperature exposure.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
44.	**Thermoplastic** A thermoplastic is like butter. You can repeatedly cause the material to move from liquid to solid, and back again, simply with the addition / removal of heat. The point at which a thermoplastic transitions from liquid to solid, or solid to liquid, is called its melting point.	SLS printed nylons, thermoplastic urethane (TPU), polystyrene are examples thermoplastics. All FDM materials are thermoplastics.
45.	**Thermoset** A thermoset is like a cake, once baked. It is not possible to return it to a liquid. A thermoset plastic does not melt to a liquid when heated. It burns/incinerates. Epoxies, non-thermoplastic polyurethane (think of foam in your car seat or a Tempurpedic mattress), non-thermoplastic polyesters are examples of common thermosets.	FIG4, SLA, MJP printed plastics are thermoset plastics
46.	**Tool-less manufacturing** The production of end-use parts without the need to create hard-tooling for the manufacturing process.	3D printing and soft-tooling can be avenues to manufacture parts without the need to create hard tooling.
47.	**UL Flammability HB** UL rated for slow horizontal burning.	Flame retardant materials are required for use in automotive, aircraft and other manufacturing industries. SLS FR1200 is an example of highly flame-retardant material
48.	**Urethanes** Polyurethane polymers are used in the manufacture of foam seating and insulation, microcellular foam seals and gaskets, spray foam, durable elastomeric wheels and tires (such as roller coaster, escalator, shopping cart, elevator, and skateboard wheels), automotive suspension bushings, high-performance adhesives, surface coatings and sealants, synthetic fibers, carpet underlay, hard-plastic parts for electronics, and more. Most polyurethanes are thermosetting polymers that do not melt when heated. Cast Urethanes are similar to hard plastic parts created by injection molding.	End users may ask for 3D printed materials that have the mechanical properties of Urethanes. With cast urethanes, the tool is a soft tool, typically made with a type of silicone mold. The mold is created via a master pattern. Master patterns for cast urethanes can be created with CNC machining or 3D Printing. Creating a cast urethane master pattern is different from the steps involved in creating hard tooling for injection molding. Cast urethanes are suited for smaller runs of parts and prototyping. Because the cost for soft tooling is lower, down in the hundreds rather than hundreds of thousands, cast urethanes are excellent resources for creators still testing product design, for one-off products, or for testing market and consumer response to a new product.

	Term and Definition	Why is it important to know what this term means? Where and how is it used?
49.	**UV** Ultraviolet. The range of electromagnetic radiation between x-rays and visible light. Sunlight contains about 10% UV light.	UV light is a range of light, and specific wavelengths within that range are used to activate the curing of the liquid resin used in SLA, FIG4, MJP.
50.	**UV stability** The ability for an item to endure exposure to being left outside	UV stability is tested using a weathometer that replicates the light, heat and humidity of an item being left outside for an approximate number of days. Highly UV stable plastics can be expected to endure years of exterior exposure
51.	**Viscosity** For liquids, it corresponds to the concept of "thickness". Higher viscosity increases the state of being thick, sticky, and semifluid in consistency, due to internal friction.	The viscosity of SLA resin is be a consideration when Quickcast patterns are being printed to allow for easier draining. Composite SLA and FIG4 resins filled with minerals/ceramics will have a higher viscosity and require thorough stirring to correctly print parts.

Lesson 5: 3D Systems Figure 4 Standalone Printer

The objective of this lesson is to introduce the learner to the Figure 4 Standalone printer.

Goals

- Identify the Figure 4 printers.
- Describe the parts of the Figure 4 Standalone printer.
- Describe the Figure 4 Standalone including its applications and use cases in various industries.

Objectives

- Identify the Figure 4 printers.
- Describe the main parts of the Figure 4 Standalone printer.
- Describe the Figure 4 Standalone including its applications and use cases in various industries.

Topics

Figure 4 Family (brief)

- Figure 4 Modular
- Figure 4 Standalone
- Figure 4 Production

Figure 4 Standalone Key Components

- Identify/Explain all the items that come with the printer and the purpose of each.

Figure 4 Standalone

- Figure 4 description, benefits, and uses (brochure)
- Figure 4 applications and use cases in various industries (marketing or other materials to reuse)
    a. Jewelry
    b. Medical
    c. Casting
    d. prototyping
- 3D Systems material data sheets – have learners try to find them and download them.

Exercises

None

Assignments

- Locate a Figure 4 use case online.
- Download a Figure 4 brochure from 3D Systems online.

Additional Resources: On Your Own

Encourage learners to find or explore these additional resources on their own time.

- Figure 4® Tutorial Module #2 - Theory of Operation (video) https://www.youtube.com/watch?v=eRRI6CfvhbA how Figure 4 works, the components, basic operation

LESSON 6: DESIGNING FOR 3D PRINTING

The objective of this lesson is to explain the geometrical concepts involved in 3D printing. Some learners may know how to design a 3D model in a CAD system. Some may not. However, they need to be taught the concept of a 3D triangle mesh, how the resolution affects surface finish, and slicing and layer thickness.

GOALS

- Identify where design takes place in the 3D printing process.
- Describe 3D printed features and basic geometry terms.
- Describe concepts and components to take into consideration when designing a part.
- Describe design-related tasks you need to complete before 3D printing.
- Describe design tools to use when 3D printing.
- Introduce Geomagic Control X, Design X, and 3D Sprint.
- Describe the importance of accuracy in design.
- Explain how the resolution affects the surface finish.

OBJECTIVES

- Describe concepts and components to take into consideration when designing a part.
- Describe design-related tasks you need to complete before 3D printing.
- Describe design tools to use when 3D printing.

TOPICS

DESIGNING FOR 3D PRINTING

- Where design takes place in the process (not in their technician workflow, though)
- Design intent
    - Design for prototype vs. design for end part
        - Example, living hinges
        - Reference MJP best practice guide
        - Sometimes 3D printing is used for end production part (in this case, designing for prototype and end part are the same)
- Design for 3D printing (introducing them as concepts and giving examples) – the 'HOW' for support structures and orientation comes later in this course
    - Layer height
        - Layer thickness and slicing
    - Support structures
        - Definition
            - Top down

        - Bottom up
      - Purpose
      - Examples
    - Part orientation
      - Definition
      - Purpose
      - Examples
    - Scaling
      - Scale factors
        - Shrinkage
      - Making scale models
    - Distortion
      - In-build curl
      - Post-build warping
- General terms
    - General
      - Materials
      - Technology
    - Part attributes
      - Wall thickness
      - Aspect ratio
      - Supported walls
      - Unsupported walls
      - Mesh
      - 3D triangle mesh
      - Embossed and engraved details
      - Fillets
      - Holes
      - Escape holes (drain holes)
      - Internal voids / hollow area
      - Pin diameter
      - Connecting/moving parts
      - Minimum feature
      - Horizontal bridges
      - Overhangs

        - Unsupported edges
        - Upface
        - Downface
    - Software/design
        - Mesh slicing
        - Brep vs. mesh model (could show on a slide (use DX), not in 3D Sprint)
        - XYZ coordinate system
        - Moving from 2D to 3D in CAD (DX)
        - Preparing a file
    - Quality assurance
        - Control X
            - Brief introduction
            - What does it mean to have accuracy in design?
        - Tolerance
        - Inspection
        - Metrology

Design Tools

- Slide of tools
- Reverse engineering

Exercises

Odd-numbered teams

3. Locate the 3D Sprint software and open it.
4. Take a moment to look around. Press F1 to open the help feature and see if you can find information on support structures. Read that brief section.

Even-numbered teams

5. Take a look at the Figure 4 printer. Without pushing any buttons, examine the outside.
6. Locate the build platform.
7. Identify post-processing tools, the cleaning station, where to dispose of waste, lab coats and safety glasses.

Then switch teams.

Assignments

None

LESSON 7: 3D SPRINT DEMONSTRATION

The objective of this lesson is to introduce learners to 3D Sprint. It should be a general overview of all the features of 3D Sprint (basically stuff from our existing documentation) and should highlight the fact that you can prepare parts for all of 3D Systems plastic printers from this one software.

GOALS

- Be aware that 3D Sprint can be used to prepare a part for all of 3D Systems plastic printers.
- Navigate in 3D Sprint to show the interface and menus.
- Demonstrate basic tasks in 3D Sprint by following the process we've established:
    - Import a CAD file into 3D Sprint.
    - Describe the CAD file in 3D Sprint.
    - Manipulate the CAD file in 3D Sprint
    - Identify possible issues with the part/file.
    - Repair issues with the part file.
    - Navigate through the interface testing the various tools
- Describe additional tools in 3D Sprint that can be used to repair or improve a part file.
- Describe special features used in 3D Sprint to prepare a part file for printing.

OBJECTIVES

1. Use 3D Sprint to import and repair a CAD file.
2. Describe additional tools in 3D Sprint that can be used to repair or improve a part file.
3. Describe special operations used in 3D Sprint to prepare a part file for printing.

TOPICS

3D SPRINT

- 3D Sprint supports all 3D Systems plastic printers
- Importing files when you receive a part request (base license; file types)
    - Broad variety of files accepted.
    - Drag and drop/ File> Import vs File> Open
- Scaling per unit
    - Between IN and MM. If parts are another unit (CM for example) conversion has to be done manually.
- Quality check
    - Good practice to run QC, some errors will cause part to be outlined in Red without running QC.
- Measure

    - Control Key unlocks the selection to be any point
- Look for errors
    - Measure wall thicknesses on small parts to make sure they resolve
    - Measure snap/ slip fit areas to make sure there is clearance
- Repair issues in the part file
    - Send part to the Prepare tab and run a fix
- Copy
    - Standard copy- just makes multiple instances
    - Linear patter makes copies in a specific direction with a specific distance between them
- Open front/back/top - views in dialog box
    - Top front Back - snaps to that view
    - Sharp edge / transparent can be useful in visualizing features
    - Clipping planes can be very useful to looking at how the part will print and looking at internal features
    - Downface shows color gradient for downfacing surfaces useful in supporting. Gradients and angle are editable
- Other key 3D Sprint features
    - Saving .3dsprint vs exporting
    - Split tool
    - Offset tool
    - Engrave tool

Demonstration

- Import a CAD file into 3D Sprint
- Describe the CAD file in 3D Sprint
- Manipulate the CAD file in 3D Sprint
- Identify possible issues with the part/file
- Repair issues with the part file
- Navigate through 3D Sprint's Prepare, Print, and Queue tabs
- Locate the various tools shown in this lesson

Exercises

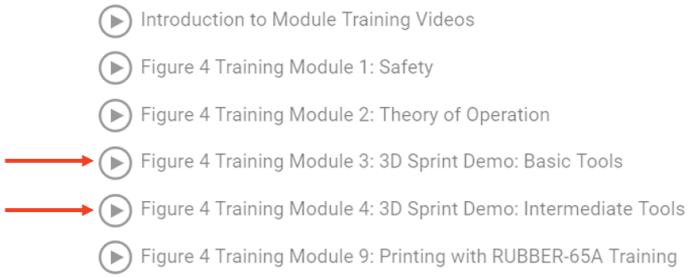
- Follow along during class in 3D Sprint using the same file as the instructor. Groups take turns working in 3D Sprint.
    - Import a file
    - Describe the CAD file in 3D Sprint

- Manipulate the CAD file in 3D Sprint
- Navigate through 3D Sprint's Prepare, Print, and Queue tabs
- Identify possible issues with a part/file that you imported
- Locate the various tools shown in this lesson

Assignments

Watch two videos. Feel free to watch all of them if you like.

http://3dsyste.ms/3ds7



Additional Resources

Encourage learners to find or explore these additional resources on their own time.

- Look at a complex part in 3D Sprint. Try to locate some of the geometries and features covered in class.
- Locate and download datasheets and brochures on Figure 4 Standalone.

3D Sprint Demonstration (Instructions)

Goals

- Import a CAD file into 3D Sprint.
- Describe the CAD file in 3D Sprint.
- Manipulate the CAD file in 3D Sprint.
- Identify possible issues with the part/file.
- Repair issues with the part file.
- Navigate through 3D Sprint's Prepare, Print, and Queue tabs.
- Locate the various tools shown in this lesson.

Demonstration Notes

Follow these instructions as you demonstrate the 3D Sprint software. The demonstration below was done for an SLA printer. You should demonstrate these steps using a Figure 4 printer file (such as ***Jewelry-Error-scan-ring01.stl***).

Introduction to 3D Printing

NOTE: Your 3D Sprint interface and process may be slightly different than this one. There are basic and pro versions of the software.

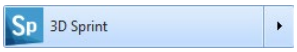
CHECKLIST

- ✓ Accessing the 3D Sprint software
- ✓ Setting Preferences
- ✓ Importing an STL file
- ✓ Interacting with the User Interface
- ✓ Reviewing the Print workspace
- ✓ Looking closer at the Main commands
- ✓ Fixing the part
- ✓ Checking for printability issues
- ✓ Optimizing the part orientation
- ✓ Using Auto Place
- ✓ Generating supports
- ✓ Estimating print time and material consumption
- ✓ Saving the project
- ✓ Preparing the Build File (BFF)
- ✓ Starting the print job

3D Sprint is a new generation printer client and 3D application. It enables fast and powerful control over the print layout and simulation as well as print job management and queue. These directions and the information contained within will introduce you to 3D Sprint.

⇨ Step 1. Access the 3D Sprint software

Method One:

- Click on  in the lower, left-hand corner of the screen
- Type **3D Sprint** in the *Search Programs and Files* field and click on 

Method Two:

- Double-click on  (3D Sprint icon) located on the Desktop

  This accesses the **Print** tab in the 3D Sprint software (Figure 1).

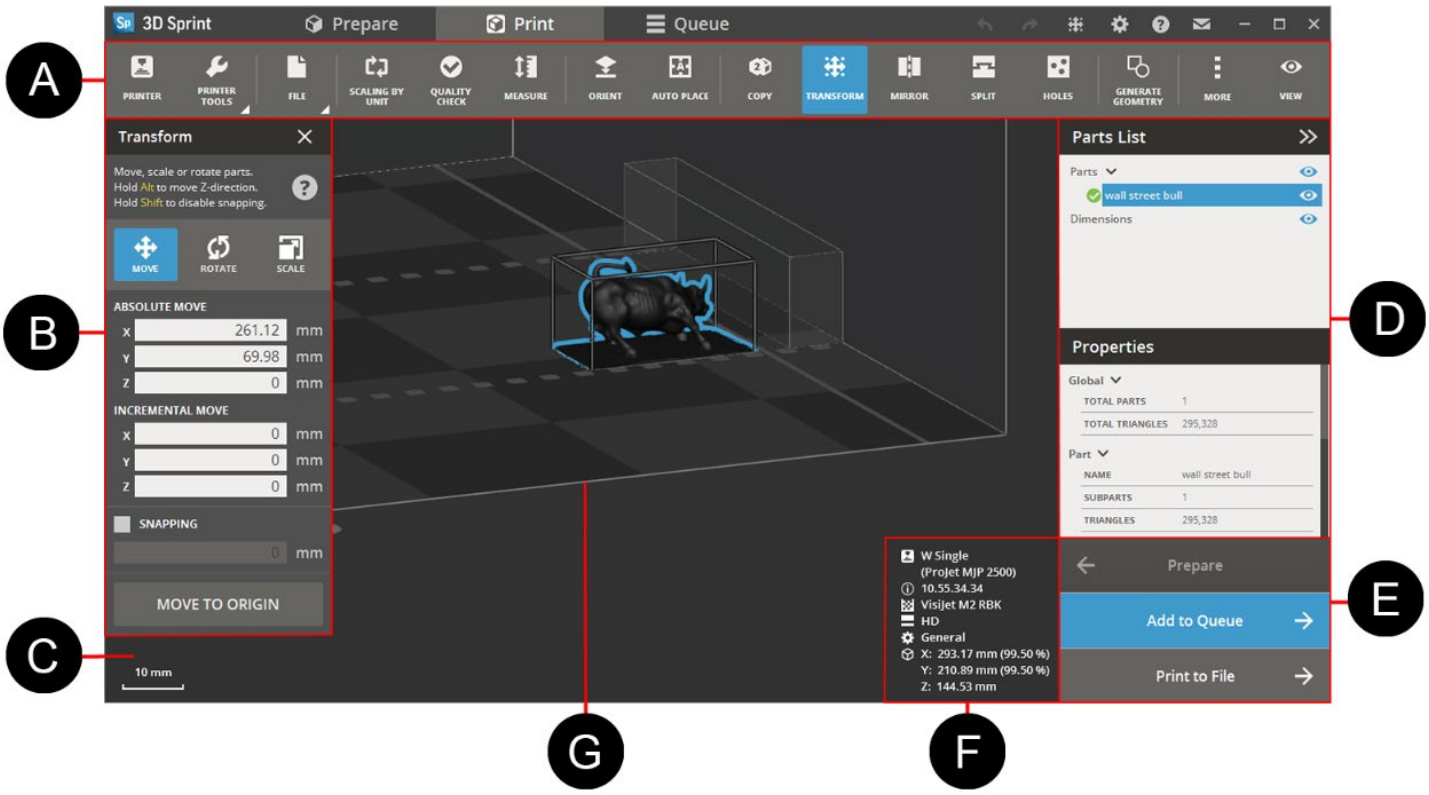


Figure 1 3D Sprint **Print** tab

Use **Print** to setup and prepare your print. To add 3D-files to the print platform, under File, click Import and navigate to your 3D file.

A. Main commands
B. Command panel
C. Scale
D. Parts List/ Properties
E. Navigation buttons
F. Selected printer information and scale
G. Print Platform

⇨ Step 2. Set Preferences (Step 2 should already have been done for you.)

- Click on  (Preferences) in the upper right hand corner of the screen.

  This opens the **Preferences** dialog (Figure 2).

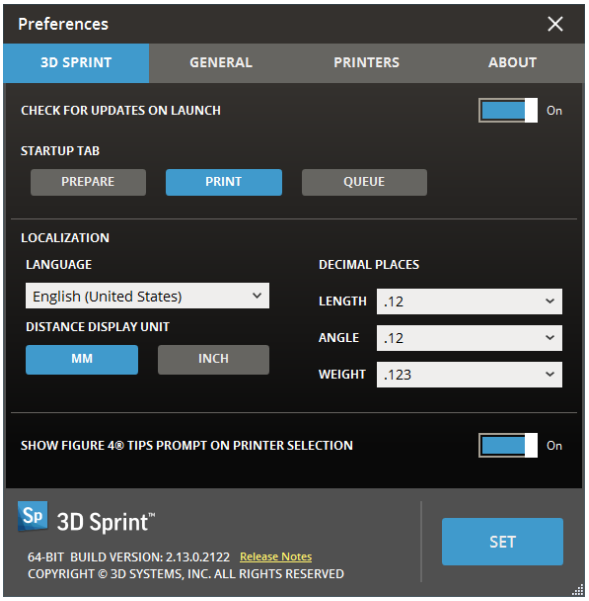


Figure 2 Preferences 3D Print tab

- Set the **Distance Display** to the desired **Units.**
- Click on the **Printers** tab (Figure 3)
- Click on the  (Eye) to the left of the printers that you would like to be hidden.

  This will hide all the printers that are not selected when setting up a printer.

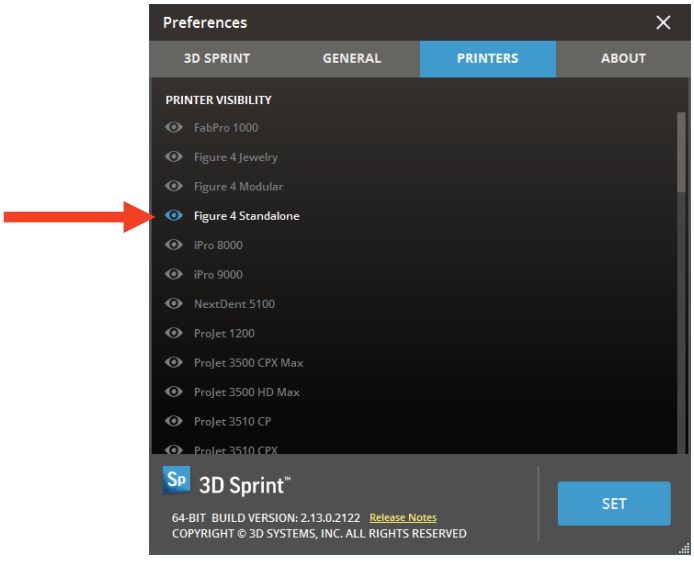
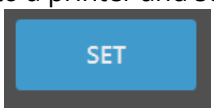


Figure 3 Preferences Printers tab

- Click on  (Printer command) in the upper left corner of the screen.

  This opens the **Printer** command used to connect to a printer and set a current printer for a print job setup. When selecting a printer, click **SET** 

to use previous or default settings, or go through each step to set up an MDM size, material, print mode and build style for the printer. The current printer is marked with **Current ★.**

  All laptops should already be set up regarding 3D Sprint settings.

⇨ Step 3. Loading an STL file

- Click on  (File Command) and select  (Import). Navigate to the folder where your STL file.
- Open the file.

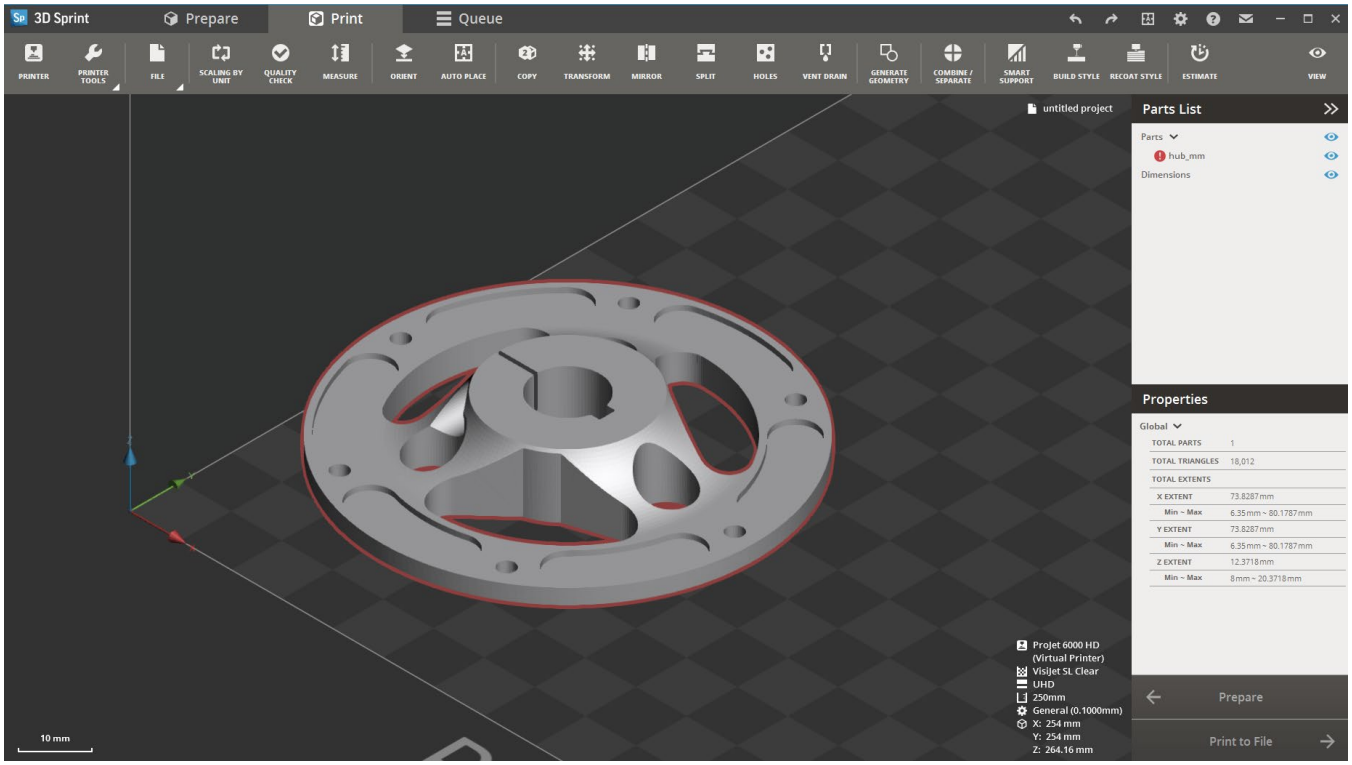
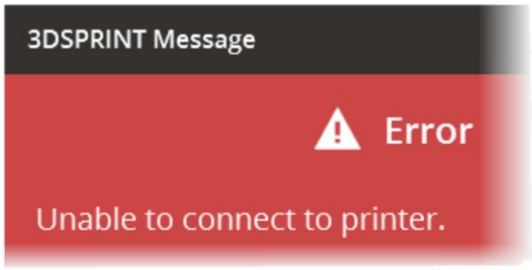


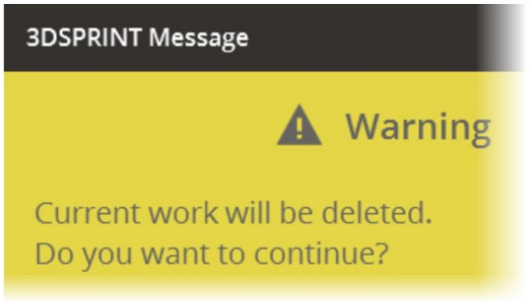
Figure 4 3D Sprint workspace with selected printer, material, print mode and build style (example)

⇨ Step 4. Interact with the User Interface

The application is intuitively guides you through the process of editing parts, setting up print jobs and managing the print queue. Several colors are used to notify you of the status:

Color	Message/ Application	Files and Parts	Print Queue
Blue	Blue marks something that calls your action, such as a button. It can also indicate selected entities or modes. 	Fixed parts are outline in blue in the 3D view. 	Selected print jobs. 

Color	Message/ Application	Files and Parts	Print Queue
Red	Signals an error that requires action 	Analyzed defective parts and files are marked red. They may need to be fixed in order to print well. Unavailable files are marked red in the Files module Files or parts list: Faces with reversed normal are red. 3D view outline: 	Failed prints are marked red. Unavailable printers are marked red 

Color	Message/ Application	Files and Parts	Print Queue
Yellow	Signals a warning that may require your action to correct. 	Files or parts that cannot be verified or have not been verified yet are marked yellow. Files or parts list: 3D view outline: 	Print jobs that require attention or incomplete print jobs 

Color	Message/ Application	Files and Parts	Print Queue
Green		Files or parts in list are marked green if fixed. 	
Color	Message/ Application	Files and Parts	Print Queue
Gray	Neutral color gives information that will not affect setup or print and indicates an unselected item or tool.	Native parts in Files module are marked gray – does not indicate part state. 	Unselected jobs that are pending or completed. 

Note	Hover the mouse over the exclamation mark to the left of the file name in the Parts list for a description of errors or improper placement.

- Practice manipulating the view of the model with the mouse

Rotate –  Right-click + drag 

Pan –  Hold <Shift> + right-click + drag

 **OR**

 Right-click, then left-click + drag (in order)

Zoom –  Scroll wheel

 **OR**

 Hold <Ctrl>, right-click + drag

Select -  Left-click to select a part or subpart 

Left-click + drag to select multiple parts with a bounding box

Left-click + <Shift> to add parts to current selection by click or drag

Left-click + <Ctrl> to toggle part selection by click or drag

Note	When using both mouse buttons to pan, click in correct order, first right-click then left-click. Parts can also be selected by clicking on their names in the **Parts List**. Hold <Shift> to add to selection, hold <Ctrl> to remove from selection

⇨ Step 5. Review the Print workspace

The Print tab is used to setup and prepare a print. It contains the Main commands, the Command panel, Scale information, Parts List/ Properties, Navigation buttons, Selected printer information and the Print Platform.

- Click on  (Auto Place)

  This opens the Auto Place dialog.

- Review the main areas of the **Print** workspace (Figure 5)

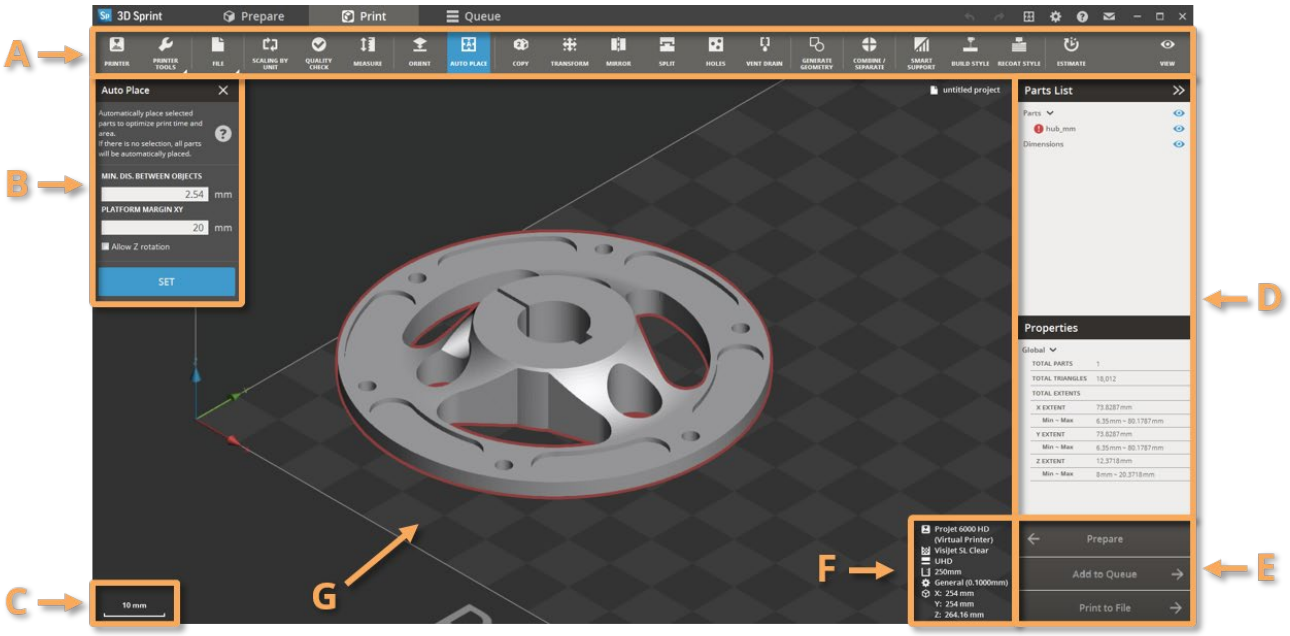


Figure 5 Main areas of the Print workspace

A. **Main commands** – commands are split into three groups: Printer, File and Other

Note	If all commands do not fit in the command bar, they will be placed under **More** to the far right of the Main commands bar.

B. **Command panel** – this is the default location of the various command panels when opened. You can click and drag these panel to a new location in the workspace or onto a separate screen.

C. **Scale** – this is the scale of the part in the viewport. It automatically adjust as you zoom in or out in the view area.

D. **Parts List/ Properties** – shows all parts, dimensions and supports on the platform and can be used to hide or show parts in the application as well as select, delete, duplicate, rename and export parts, dimensions and supports.

E. **Navigation buttons** – use **Prepare** to prepare a part, send the print setup to the print Queue by clicking on **Add to Queue** or create a BFF file by clicking on **Print to File.**

F. **Selected printer information** – information about the current printer, material, print mode and net printable size after applied shrinkage factor.

G. **Print Platform** – represents the current printer platform in the viewport with the Origin and a grid that indicates the relative size and location of the parts.

Note	Use the Measure command or reference Properties for exact part measurements.

⇨ Step 6. Examine the Main commands

Hover the mouse over each command to read a brief description.

Printer:

Printer - manage printers and set current printer

Printer Tools – set custom printer settings, check material cartridge and save current printer logs

File:

Open – Open a 3D Sprint file

Save – Save the project as a 3D Sprint File

Save As – Save the project as a 3D Sprint File

Import – Import parts into a project

Export – Export selected parts to a desired file format, all parts will be exported if none are selected

Delete – Delete selected parts, <Backspace> or the <Del> key do the same

Close – start a new project

Other:

Scaling by Unit – select a part and select the units to scale it to

Quality Check - check part quality for volume, wall thickness, gap clearance, interlocked/ enclosed, voids, drainability, open boundaries, defects and collisions

Measure - measure part distance, angle or radius by selecting corner points, lines or faces

Orient – automatically orient parts or select a face to align with the print platform

Auto Place – automatically place selected parts to optimize print time and area. If there is no selection, all parts will be automatically placed

Copy – copy a part and place automatically or create a linear pattern

Transform – Move, Scale or Rotate parts with the mouse in the viewport or type in absolute or incremental values.

Mirror – create a mirrored part

Split – split a part using a plane or line cut

Holes – Make a part hollow with a set wall thickness and add drain holes to allow material to drain in post-processing

Vent Drain – generate air vents and material drains for QuickCast patterns

Generate Geometry – create a box or cylinder geometry

Combine/ Separate – combine or separate multiple parts or shells

Smart Support – automatically generate a support structure to hold the first layers in place, prevent curl and create a separation between the part and the platform for easier removal

Build Style – edit build parameters, change the Build Style or Save/ Import/ Export custom Build styles

Recoat Style – assign recoat styles to the print that will define the behavior of the layer additive process during the print

View Slice – view selected slices in the BFF or SLI file by dragging the top/bottom plane in the viewport or adjusting the top/bottom ranges on the slider bar to the left of the Parts List

Estimate – calculate the total print time and material consumption for the print setup

View – opens the View panel that allows for the manipulation of the view through Zoom, Shading, Down Face, View Mode, View, Clipping, Slice Shading/ Sampling Rate and Platform Grid Size

⇨ Step 7. Fix the part

Depending on the source (3D scan data, CAD file tessellation, Voxel/ organic modeling), the mesh data may have inherit errors or deficiencies. The mesh consists of triangles; three vertices make up a face. The part mesh should be closed without errors for attempting to print it. If the mesh has errors, such as holes or flipped faces, unexpected printing results may occur.

- Click on the part

Note	The red, yellow or blue outline around the part will appear brighter when the part is selected.

- Click the 

navigation button in the lower right corner of the screen

  This sends the selected part to the **Prepare** workspace.

- Click on  (Fix)

  This opens the Fix command.

- Review the main areas of the **Prepare** workspace (Figure 6).

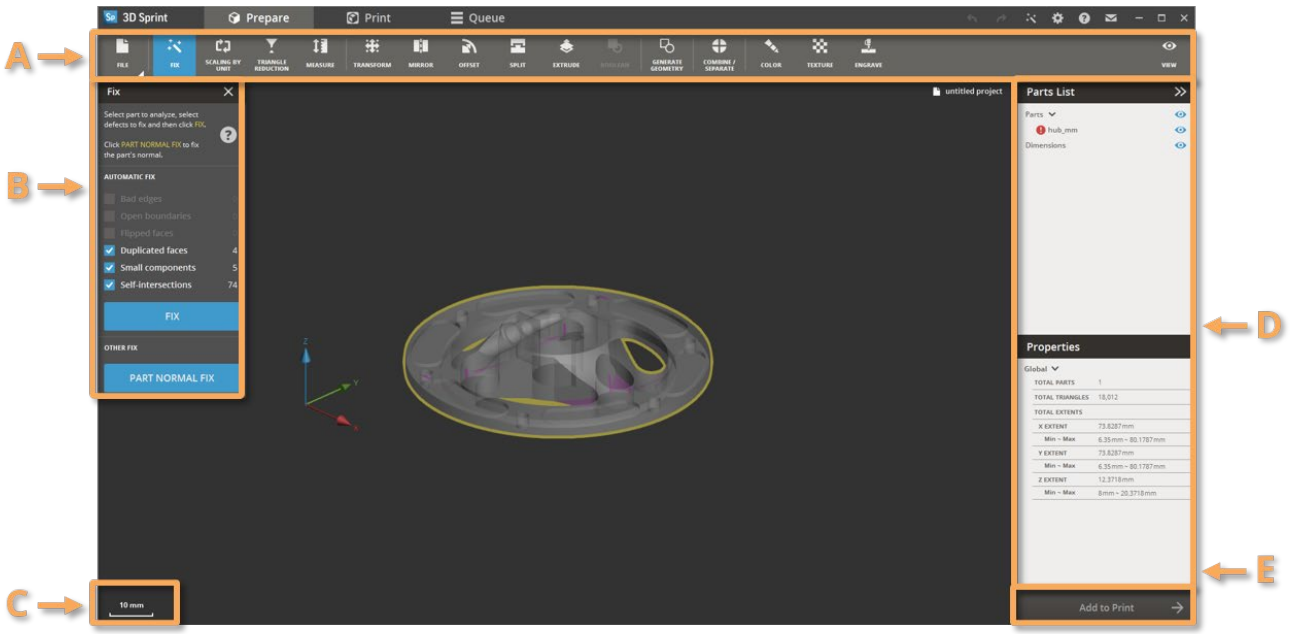


Figure 6 Main areas of the Prepare workplace

A. **Main commands** – commands are split into three groups: Printer, File and Other

Note	If all commands do not fit in the command bar, they will be placed under **More** to the far right of the Main commands bar.

B. **Command panel** – this is the default location of the various command panels when opened. You can click and drag these panel to a new location in the workspace or onto a separate screen.

C. **Scale** – this is the scale of the part in the viewport. It automatically adjust as you zoom in or out in the view area.

D. **Parts List/ Properties** – shows the part dimensions and can be used to hide or show parts in the application as well as select, delete, duplicate, rename and export parts, dimensions and supports.

E. **Add to Print** – send the part back to the Print workspace

- Make sure the part is still selected
- Notice that the part is outlined in yellow and Self-intersections are highlighted (Figure 7).
- Click FIX (Fix button)

  This analyzes and fixes the part mesh and if successful outlines the part in blue (Figure 8).

Note	If this part has inverted normal faces they would be marked in red. Use the Part Normal Fix option when entire subparts have flipped normals. Otherwise, use the Fix option to automatically repair normal along with other defects.

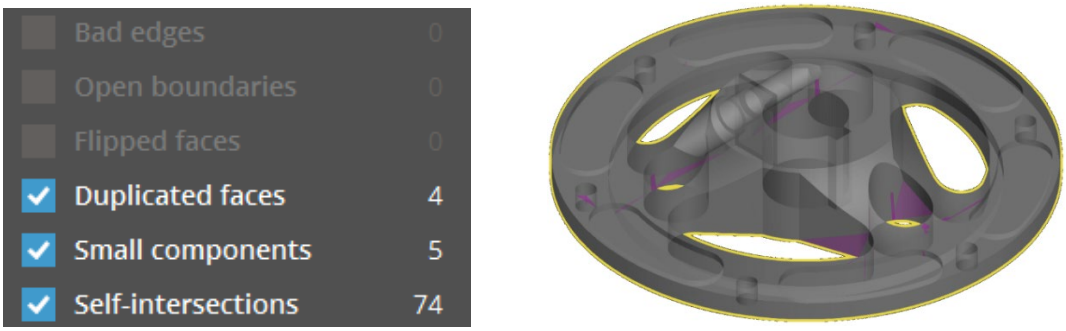


Figure 7 Before Automatic Fix

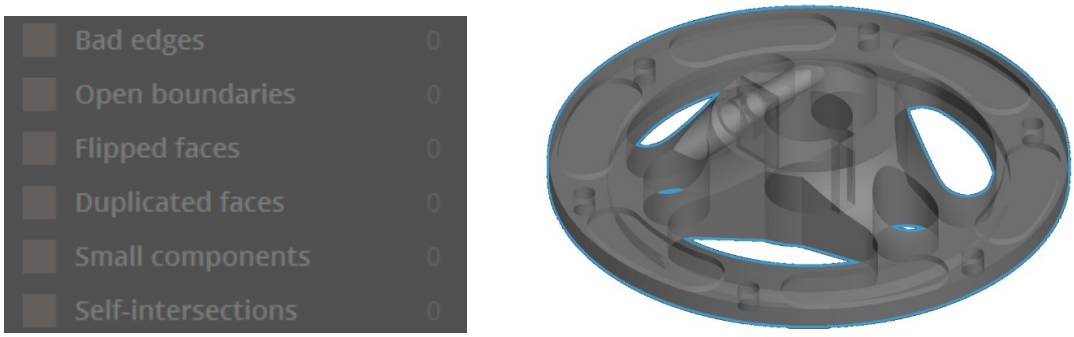


Figure 8 After Automatic Fix

- Review the different defects that will automatically be fixed

  A. **Bad edges** – non-manifold edges where the vertices of the triangles on meeting surfaces do not align

  B. **Open boundaries** – missing surfaces in the mesh

  C. **Flipped faces** – faces with inverted normal direction

  D. **Duplicated faces** – duplicated faces

  E. **Small components** – features that may be too small to print in set mode

  F. **Self-intersections** – areas where faces intersect each other

Note	Not all defects can be fixed. Always check the resulting part after running the command.

- Click on the X in the upper right corner of the **Fix** dialog to close the command
- Make sure the part is highlighted and click on 

(Add to Print)

  This sends the part back to the **Print** workspace.

⇨ Step 8. Check for printability issues

Quality Check analyzes the current print setup for printability issues. It looks for areas or features in the part that might not print well or cause issues when printing.

Note	Quality Check is just an indication of possible printability issues. It does not prevent the print setup from being printed.

- Click on  (Quality Check)

  This opens the Quality Check command (Figure 9)
- To check the printability, select attributes to check from the View Attributes list
- Click 

(Check button)

  All attributes that pass are marked with a  (Figure 10)

  Errors are marked with an 
- Select the **Attribute** to see the affected area in red (Figure 10)
- See detailed information under **Details** including exact threshold value and the percentage of data in error

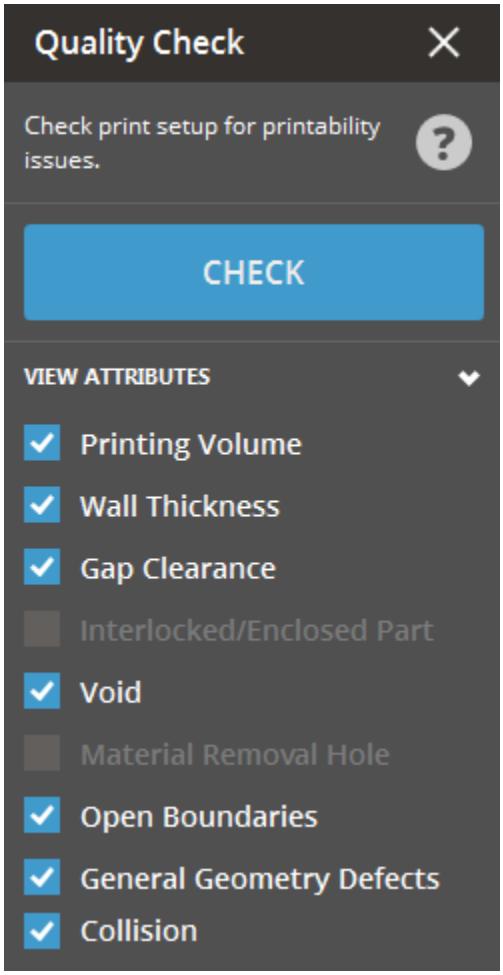


Figure 9 Quality Check command

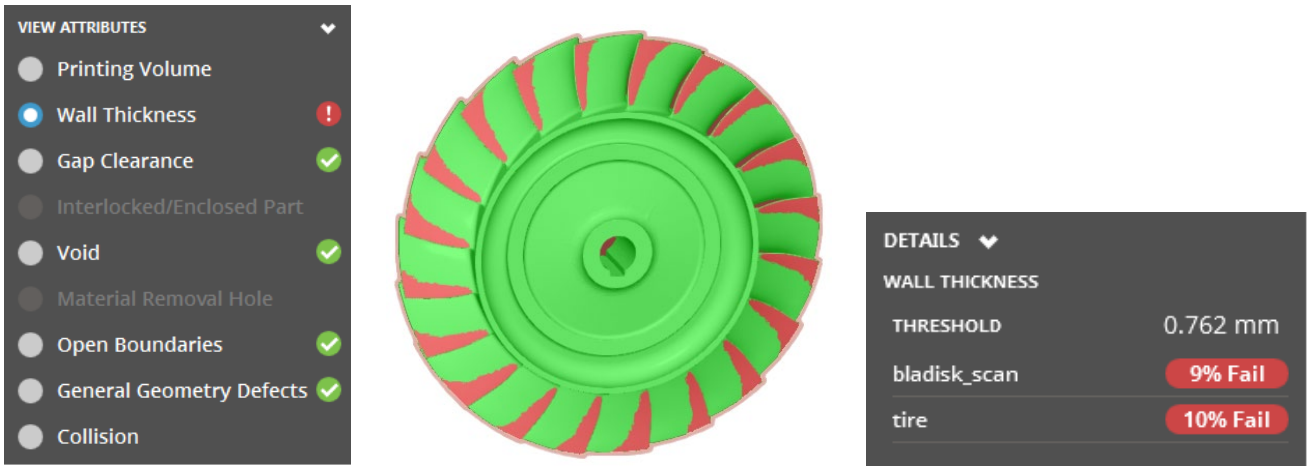
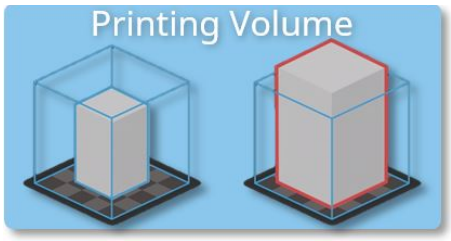
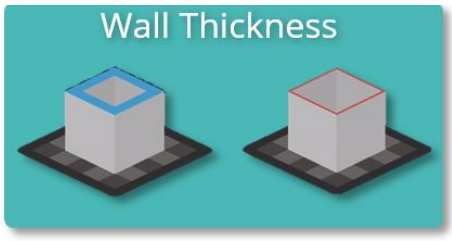


Figure 10 View Attributes

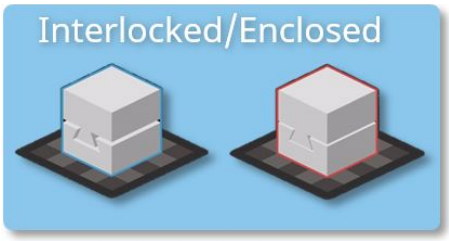


Parts do not fit within the printing volume.

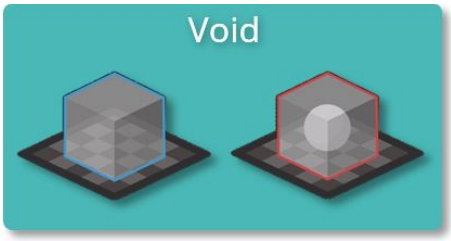


Thin inner mesh distance that may cause printing issues with the currently selected printer and print mode. A feature that is too thin can collapse or be omitted when printing.

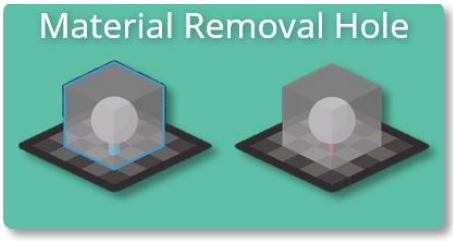
Gaps in the mesh that are too narrow to print. The gaps might be fused together when printing.



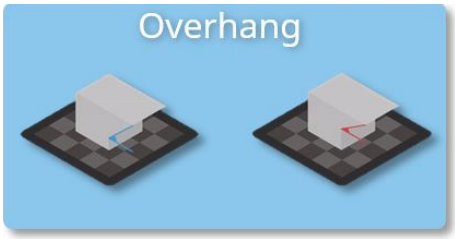
Interlocked gap between parts is too small to remove support material or might be fused together when printing.



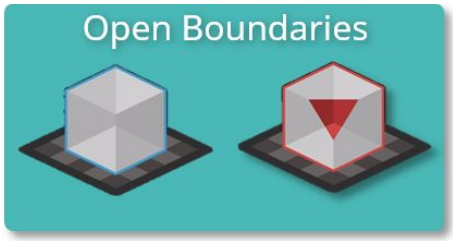
Enclosed volume within a part. This volume might be filled with uncured print material or support material which cannot be removed.



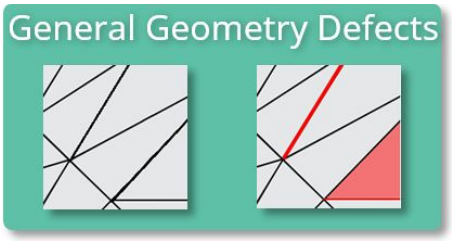
Material removal holes are too small to remove uncured material after printing.



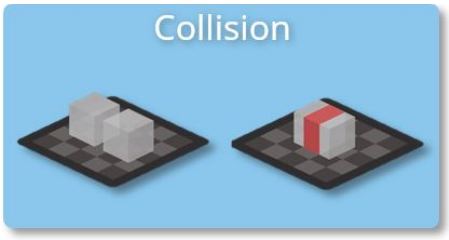
Overhangs might require a support structure because of low angle or overhang distance.



Open boundaries in part mesh, holes in the part mesh that need to be repaired. It can create errors in the slicing process and can even cause the print to fail



Defects in the part mesh such as bad edges, open boundaries, flipped faces, duplicate faces and small components.



Parts are overlapping each other.
Use Auto Place or Transform
commands to resolve the collision.

⇨ Step 9. Optimize the part orientation

A selected part can be automatically re-oriented for **Print Time**, **Surface Quality** or **Support Area** or by selecting a face on the part to align with the print platform. The Overhang Angle Criteria sets the angel that requires supports to print. If the orientation is not as expected, change the option and click Orient again or use Manual orient.

- Click on  (Orient)

  This opens the **Orient** command (Figure 11)
- Make sure a part is selected
- Click on 

(Manual tab) (Figure 12)

  This orient option allows you to select a facet to align with the print platform. You will notice that a blue spot appears and highlights a facet when you hover the mouse over the part.
- Click on any facet on the part to orient that face parallel with the print platform
- Click on 

(Set Base button) to choose another facet
- Click on 

(Auto tab)

  This switches to the automatic part orientation options.
- Mark the radio button to the left of **Support Area**
- Click 

(Orient button)

  This orients the part at an angle to minimize the amount of supports needed to print the part
- Mark the radio button to the left of **Surface Quality**
- Click 

(Orient button) again

  This re-orients the part flat to put most of the circular geometry in the plane of the resin for better accuracy with less stair-stepping.
- Mark the radio button to the left of **Print Time**
- Click 

(Orient button) again

  This also orients the part flat to minimize the amount of layers needed to print the part.

Note	If orienting multiple parts, make sure that they do not collide after running the Orient command.

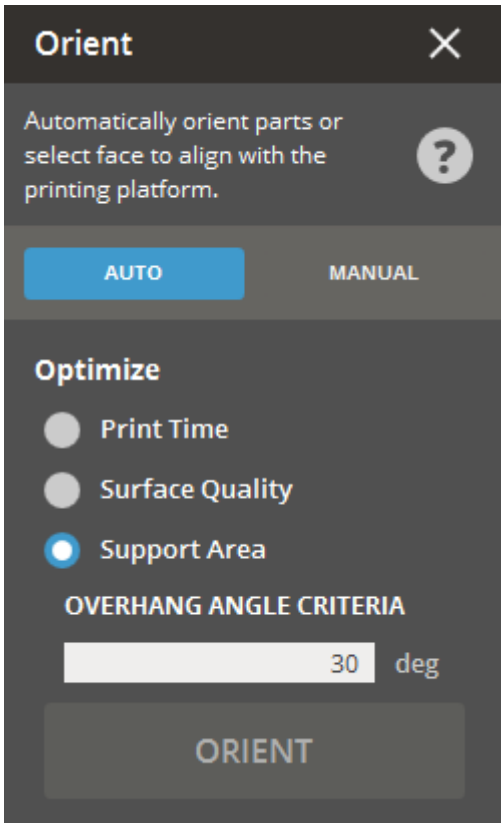


Figure 11 Orient Auto command

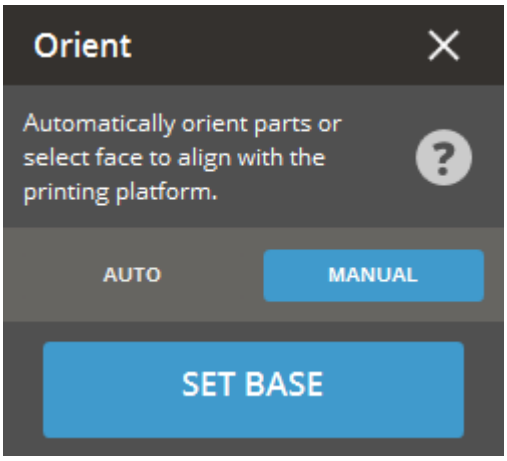


Figure 12 Orient Manual command

⇨ Step 10. Use Auto Place

The part is still outlined in red, because it still needs to be placed within the print volume at a minimum Z height to allow space for supports (Figure 3.14)

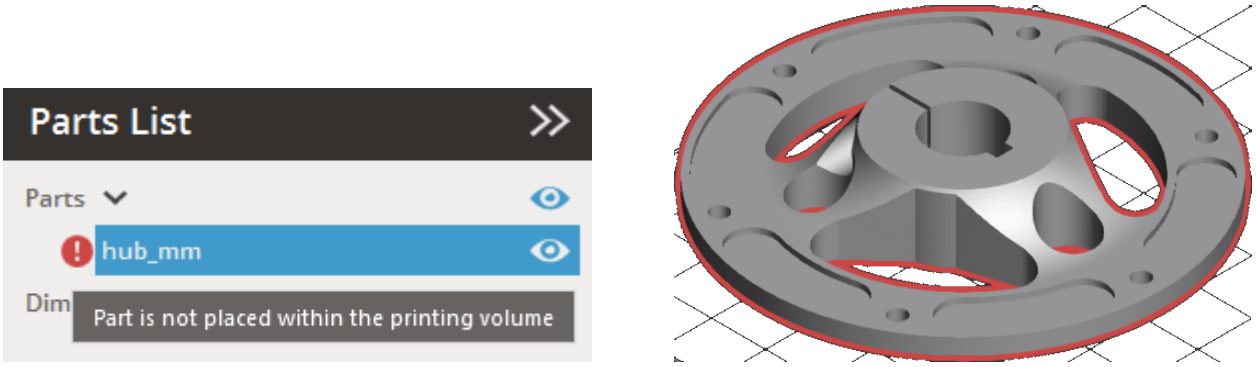


Figure 13 Part is not placed within the printing volume

- Click  (Auto Place)
- This opens the **Auto Place** command (Figure 14)

  Here you can set the minimum distance between parts and the amount of margin around the outside of the print area. You can also choose whether or not to allow for Z rotation during placement.

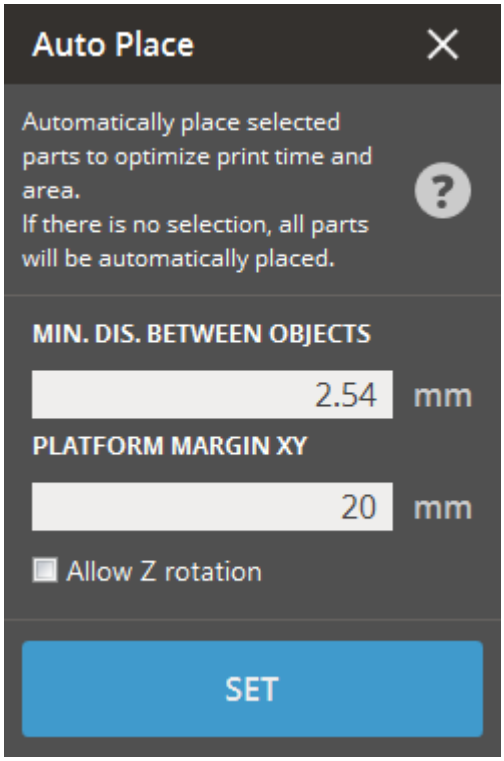


Figure 14 Auto Place command

- Click on 

(Set button)

  The selected part(s) are automatically placed to optimize print time and area.

Note	If there is no part selected, all parts will automatically be placed.

- Note that the part is now outlined in blue and there is a green checkmark to the left of the name in the Parts List (Figure 15)

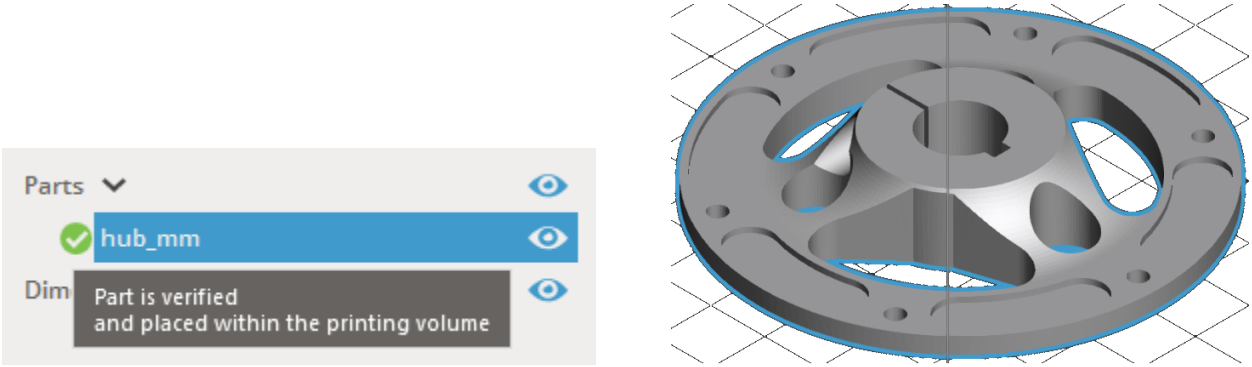


Figure 15 Part is placed within the printing volume

⇨ Step 11. Generate supports

What are Supports?

The scaffold-like structures generated by the 3D Sprint software that are attached to the down-facing regions of the part are called Supports. Supports provide a breakaway region between the print platform and the part, anchor the first layers of down facing surfaces to the platform, and buttress areas that would otherwise sag, distort or separate.

To automatically generate supports:

1. Click  (Smart Support)

   This opens the Smart Support command (Figure 16)

- Click 

(Create Supports button)

  Supports are automatically generated using default parameters (Figure 17)

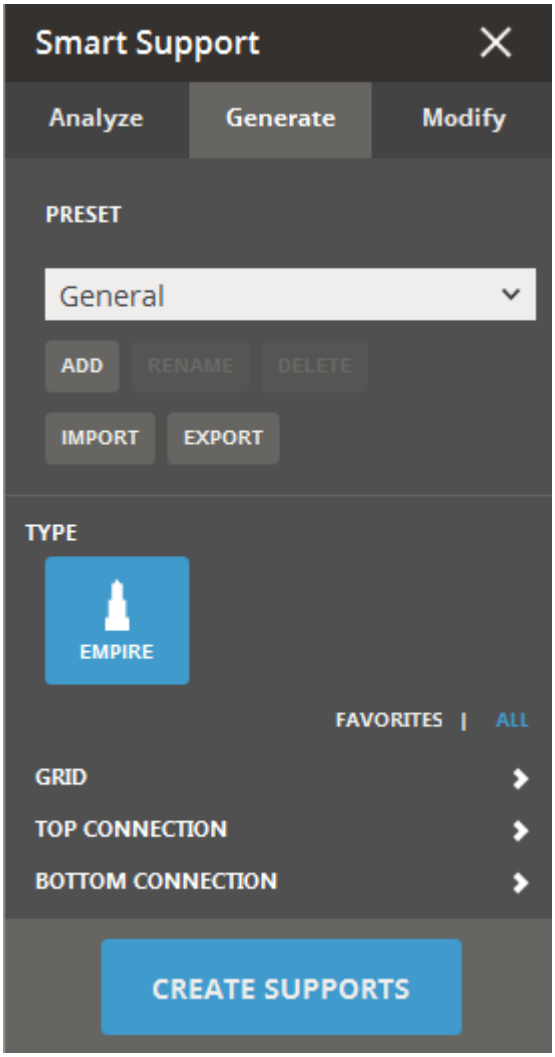


Figure 16 Smart Support command

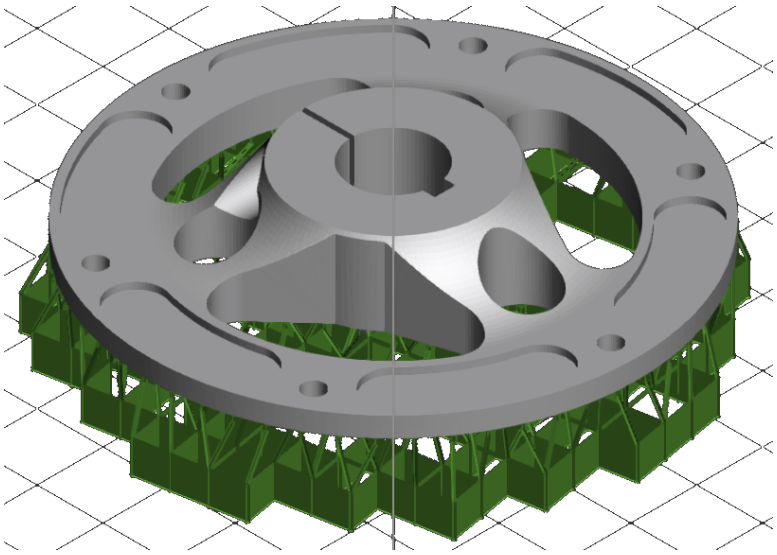


Figure 17 Supports (example)

⇨ Step 12. Estimate print time and material consumption

2. Click  (Estimate)

   This opens the Estimate command and displays the estimated print time and material usage (Figure 18)

- Close the Estimate command by clicking on the X in the upper right hand corner of the dialog

Note	Estimated print time and material usage may differ from the actual values.

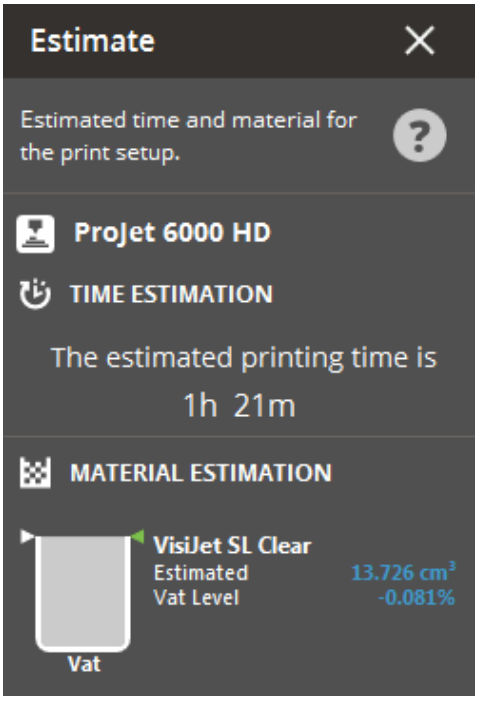


Figure 18 Estimate command

⇨ Step 13. Saving the project

You can save the current project to a native **.3dprint** file which can be used to save a print project for later or share the print. This native file contains the entire project, print setup and file preparations including part data.

- Click  (File)

  This opens the File drop down menu.

- Select  (Save As)

  The **Save As** dialog will appear.

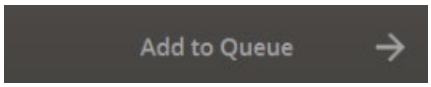
- Name the project.
- Click **Save** button

⇨ Step 14. Prepare the Build File

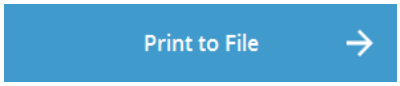
The final step in preparing the part(s) for printing on the printer is to prepare a build file. Often referred to as Slicing, this last step converts the STL file(s) into a series of stacked, cross-sectional layers and converges the objects into a single optimized print format called the BFF (Build File Format).

Note	Prior to adding the project to the Queue or printing it to File, make sure that all of the objects on the platform are supported and that all supports and parts are within the extents of the print tray.

There are two ways to create a build file (BFF):

- **Add to Queue –** use this option when you are connected to the printer.
  - Click 

(Add to Queue)

    You will be prompted to save a BFF file. The BFF file will be generated and added to the **Queue** workspace and to the **Prints** list on the printer.
- **Print to File –** use this option to create a BFF file to transfer by thumb drive to the printer.
  - Click 

(Print to File)

    You will be prompted to save a BFF file. The BFF file will be generated and a Print to File message will appear with the saved location when completed.

Note	The directory path to the BFF is hyperlinked in the 3D Sprint Message making it convenient to retrieve the file to copy it to a thumb drive or attach to an email.

⇨ Step 15. Start the print job

After the print job has been submitted to the printer, the touch display on the printer is used to start it.

Lesson 8: Workflow Step 1: Select/Confirm the Material and Printer

Goals

- Explain what to do first when you receive a part request.
- Explain how to choose a printer technology and material.
- Confirm that the printer and material chosen are the correct choice.
- Remind learners of job aids when choosing a material and a technology/printer.
- Describe a few use cases for our printers that highlight success stories and unique uses of our printers.
- Import a CAD file into 3D Sprint.
- Examine a CAD file in 3D Sprint in order to confirm/select the printer and material.
- Access 3D Systems material data sheets.
- Describe each Figure 4 Standalone material.
- Explain the material properties (in terms of function and performance) for Figure 4 Standalone materials based on the material data sheets.

Objectives

- Explain how to choose a printer technology and material.
- Access 3D Systems material data sheets.
- Use material data sheets to describe each Figure 4 Standalone material and its properties.

Topics

Select Material and Printer

- What do you do first? Take a look at your part. Import the .stl file into 3D Sprint.
- Examine the part. Is it printable?
- Confirm the material/printer; stress iterative process
- Consider the material properties required

How to select a material and printer

- Selection process
    - Decision tree
    - 3D Systems material selection guide

Figure 4 materials

- Elastomeric
    - Figure 4 RUBBER-BLK 10
        - Pros; key/best properties

        - Use case or example
    - Figure 4 RUBBER-65A BLK
- Medical
    - Figure 4 MED-WHT 10
    - Figure 4 MED-AMB 10
- General purpose prototyping
    - Figure 4 PRO-BLK 10
    - Figure 4 TOUGH-BLK 20
    - Figure 4 FLEX BLK-20
- Jewelry
    - Figure 4 JEWEL MASTER GRY
- Key (some) material properties that impact performance, and how

Figure 4 (an example)

- Receive a part request
- Examine part file, confirm material and printer choice
- Why did we choose Figure 4 Standalone for this course?
- Expectation: Fig4 not ideal for larger volume parts

Demonstration

1. Read the part order form and analyze the part request.
2. Prioritize part requirements.
3. Use the various material selection guides/tools to identify the correct technology, printer, and material.

Exercises

- Lesson 8 Exercise – Select/Confirm the Material and Printer

Assignments

- Search for the 3D Systems Figure 4 Material Selection Guide
- Search for the 3D Systems Material Buyer's Guide
- Figure 4® Tutorial Module #2 - Theory of Operation https://bit.ly/38d1Czh

Figure 4® Basic Theory of Operation

The basic theory of operation is based on a number of principles. These consists of:

1. Define the part intent or application of the part
2. Prepare the part in 3D Sprint
3. Select material for part intent
4. Elevator system provides Z-axis motion to create the print
5. Light source and digital projection to polymerize material
6. Post Process part

https://www.youtube.com/watch?v=eRRI6CfvhbA

- Figure 4® Isotropic Properties https://bit.ly/2CXyCjt

  https://www.youtube.com/watch?list=RDCMUCsx-A5uSO_gYgi5A4RXFCag&v=ertFjtVtO_8&feature=emb_rel_end

LESSON 9: WORKFLOW STEP 2: IMPORT, EXAMINE, AND REPAIR THE PART FILE

GOALS

- Use 3D Sprint to prepare a file for printing on the Figure 4.
    - Import a CAD file into 3D Sprint.
    - Describe the CAD file in 3D Sprint.
    - Identify possible issues with the part/file.
    - Manipulate the part file in 3D Sprint.
    - Repair issues with the part file.
- Describe design considerations for Figure 4 Standalone.

OBJECTIVES

- Use 3D Sprint to import and repair a CAD file.
- Describe design considerations for Figure 4 Standalone.

TOPICS

3D SPRINT REVIEW AND PREPARE LEARNERS FOR WORKING IN 3D SPRINT

- Import a CAD file into 3D Sprint.
- Navigate 3D Sprint
- Describe the CAD file in 3D Sprint.
- Assess the part for errors
    - How to use 3D Sprint to identify possible issues with the part/file.
        - 

6 issues
        - Prepare tab – fixes multiple file errors
            - 3 showstoppers
        - Quality tab
        - Part outlined in red if it has one of three issues
- Repair issues with the part file.
    - How to resolve issues
- View files with various issues.
- Manipulate the part file in 3D Sprint.
- Learners perform exercise and report their findings.

Designing for Figure 4 Standalone

- Special aspects of designing for Figure 4 Standalone, at this point in the process.
    - Challenges/considerations and how to alleviate
        - Orientation and how to attach supports
        - Minimal cross section
        - Trapped volume considerations

Demonstration

- Import a CAD file into 3D Sprint.
- Describe the CAD file in 3D Sprint.
- Assess the part for errors.
- Repair issues with the part file.

Exercises

- Lesson 9 Exercise: Import, Examine, and Repair a Part File
- Learners perform exercise and report their findings.

Assignments

None

Lesson 10: Workflow Step 3: Orient the Part and Create Support Structures

The objective of this lesson is to teach the learner the guidelines on part orientation for the Figure 4 Standalone. Learners will get a chance to practice orienting a part file.

Goals

- Explain what part orientation means and why it's important.
- Use tools in 3D Sprint to orient a part file from your instructor.
- Review examples of parts that are correctly oriented, as well as some that are not oriented and are incorrectly oriented.
- Explain what support structures are and their importance.
- Explain what happens if you do not use support structures when they're needed, or if they are used incorrectly.
- Describe how to build support structures for a part.
- Identify cases in which support structures are needed and not needed.
- Use 3D Sprint tools to add support structures to a part file.
- Confirm that your support structures are properly created.
- Estimate cost in 3D Sprint.
- Explain what happens to support structures after a part is printed.
- Describe design considerations for Figure 4 Standalone.

Objectives

- Use tools in 3D Sprint to properly orient a part and build support structures.
- Identify cases in which support structures are needed and not needed.
- Build a cost estimation in 3D Sprint.
- Explain what happens to support structures after a part is printed.

Topics

Part Orientation

- Definition
    - Autoplace (location)
    - Orientation (rotation)
- Importance; why do it?
- How to do it
- Orientation considerations
    - Support structures; brief explanation; next lesson
    - Reducing surface area
    - Pixel resolution concerns, voxels

    - Drainage / drain holes
- Demonstrate with x different part files or images
    - Auto (we have 3D Sprint videos)
        - Don't always count on this; where it works well, when not
        - Use as a starting point
    - Manual
    - Examples of under supported, over supported, and others
- How to check to see if a part file is properly oriented

Orientation and Support Structures

- Definition and importance (reasons why you need them) of support structures
    - Some technologies do not require supports (table showing technologies that do/do not require supports)
    - Show supporting same part in different technologies
- Support considerations while orienting
    - Be careful not to over support
- Gate supports
- Parameters; overview and some basic examples
    - Basic structures
    - Key parameters, if needed
    - Hollow sections
- Tools and optimizing supports
    - Downface tool (**video available 3D Sprint video channel**); make sure you get the supports you need, and not over support
    - Z Clipping tool
        - modify tab (smart support dialog)
- Default styles in 3D Sprint; support structures
    - May be based on material you're using
    - Different styles for different uses
- Confirm that your support structures are properly created (software will default to an appropriate support structures)
    - You can modify them to better support part
- How to remove support structures
- Create support structures for a file from the instructor

- http://infocenter.3dsystems.com/videolibrary/figure-4-training-videos/figure-4-standalone/3d-sprint/best-practices#vid01

- Demonstration on adding support structures

Demonstration

- Demonstration to review part orientation
- Learners orient part files.
- Demonstration on adding support structures for another file
- Build support structures for the file
- Confirm that your support structures are properly created

Source: Designing for Figure 4 Standalone

- Support structures
- Part orientation
- Hollow sections

Cost Estimation

- How orient, create support structures impact cost
    - Risk of fail a part; over support better
    - Able to post-process

Demonstration

- Orient a part file.
- Add support structures for a part file.

Exercises

- Lesson 10 Exercise – Orient the Part and Create Support Structures

Assignments (Optional)

- Read "*How does part orientation affect your 3D printed parts?*" by Sculpteo https://bit.ly/2ZrAvfB
- Read "*How does part orientation affect a 3D print?*"
  by 3D Hubs https://bit.ly/2AiLrnn
- Browse the 3D Sprint Help site https://rebrand.ly/1345yl3

- Review today's videos and watch additional videos on Figure 4 Standalone https://rebrand.ly/umkv5cw

LESSON 11: WORKFLOW STEP 4: PRINT THE PART

This lesson describes the tasks involved in preparing to print the part with a focus on safety.

GOALS

- Review what needs to be done before you print a part.
- Describe safety protocols for working with the material and the printer.
- Identify proper safety equipment.
- Use a safety data sheet to locate safety information.
- Describe what to look for while your part is printing on a Figure 4 Standalone printer.
- Explain what to do when your print job is finished.
- Prepare for the mid-term quiz, next lesson (Lesson 12).

OBJECTIVES

- Use a safety data sheet to locate safety information.
- Describe safety protocols and equipment to use when working with the material and the printer.
- Describe what to look for while your part is printing on a Figure 4 Standalone printer.
- Explain what to do when your print job is finished.

TOPICS

SAFETY

- Material Safety Data Sheets (MSDS)
    - Safety protocols; your health and safety
- safety equipment (PPE) personal protective equipment
    - nitrile gloves
    - safety glasses
    - other accessories
- cleanliness
    - tools
    - equipment/machine
    - helps with safety / to protect yourself
    - access to soap and water

BEFORE YOU PRINT

- Check printer to make sure platform is in and clean
    - Make sure the printer is on
    - Add materials, if needed (make sure the tray is full)
- Use 3D Sprint to send the file to the printer. (transfer)

    - Add to Queue within 3D Sprint (recommended)
    - Use a usb drive to send the file to the printer. (second option)
- Demonstrate how to prepare the printer to print a part.

During Printing

- Monitor printer for any issues that may occur
    - At first, you won't see anything (how it progresses)
    - Issues
        - Nothing is attached to the platform
        - Only supports are attached to the platform, no part
        - Supports show, but some of the part is not building correctly
        - Shifting or wobbling part/structure

Post-processing methods

- Research and discuss the post-processing methods that the learners researched.

Demonstration

- Explain the process that takes place when a part is finished printing.
- Remove the platform.
- Remove the part from the platform.
- Leave the part to dry
- Remove the support structures.

Exercises

- Make sure your file is ready to print. All teams should be ready to print before the end of this class session. However, only the instructor will print.

Assignments

- Review your Learner Guide, notes, and handouts to prepare for the quiz. Quiz has 20 questions. The quiz contains questions on these topics:
    - Safety
    - Figure 4 Standalone
    - 3D Sprint
    - Workflow and processes

Additional Resources

Encourage learners to find or explore these additional resources on their own time.

- http://infocenter.3dsystems.com/videolibrary/figure-4-training-videos/figure-4-standalone/3d-sprint/setting-print-job-3d-sprint

- [ ] Setting Up a Print Job with 3D Sprint
- [ ] Accuracy Wizard
- [ ] Application Guides
- [ ] Best Practices

LESSON 12: WORKFLOW STEP 5: POST-PROCESSING

GOALS

- Discuss post-processing options.
- View a post-processing demonstration.

OBJECTIVES

- Describe post-processing options.

INTRODUCTION TO 3D PRINTING – MID-TERM QUIZ – ANSWER KEY

10 Questions Covering Lessons 1-11

The questions and correct answers (bold) are shown here.

Print the separate file (**Mid-Term Quiz - Introduction to 3D Printing (Learners).docx or .pdf**) for learners to administer the quiz.

1. __B___ Which type of manufacturing is 3D printing?
   - A. Subtractive
   - **B. Additive**
   - C. Formative
   - D. Negative

2. __D___ Which source provides the HDT for a particular material?
   - A. Figure 4 Standalone User Guide
   - B. Safety Data Sheet
   - C. 3D Sprint User Guide
   - **D. Data Sheet**

3. __B___ What is the most important goal of selecting a material and printer for a part request?
   - A. Printing the part with the highest quality
   - **B. Meeting the customer's part requirements**
   - C. Using the material that the customer requested
   - D. Making sure the part fits on the build platform

4. __C___ Which material property measures the resistance of a material to breaking under tension?
   - A. Flexural Strength
   - B. Flexural Modulus
   - **C. Tensile Strength**
   - D. Tensile Modulus

5. __D___ Which type of glove is required to be worn when working with materials?
   - A. Cotton
   - B. Rubber
   - C. Latex
   - **D. Nitrile**

6. __A___ What term is used to describe material that on first exposure to your skin causes little or no reactions, but upon repeated exposure may cause a marked response not necessarily limited to the contact site?
   - **A. Sensitizer**
   - B. Sacrificial
   - C. Prototyping
   - D. Curing

7. __B___ What should you do if a particularly large amount of resin gets accidentally splashed onto your clothes?
   - A. Immediately apply IPA to the spot on your clothes until the resin is removed
   - **B. Remove the clothing immediately, and discard the clothing according to all local, state, and federal regulations**
   - C. Apply warm water with soap to the spot and scrub the resin off
   - D. Wipe the resin off with dry paper towels, then run your clothes through a washing machine

8. __C___ Which material does the Figure 4 Standalone use to print 3D parts?
   - A. Organics
   - B. Non-Ferrous Metals
   - **C. Photo Polymers**
   - D. Ceramics

9. __A___ Which tab in 3D Sprint contains the Orient and Smart Support functions?
   - **A. Print**
   - B. Prepare
   - C. Queue
   - D. Auto Place

10. __C___ What is the main role of the 3D Printing Technician?
    - A. Designs parts in CAD software
    - B. Provides material and printer advice to get the best results
    - **C. Prints parts to fulfill part requests**
    - D. Measures the part against specifications

Topics

Post-Processing

- Define post-processing.
- Post-processing/finishing available in AM.
- List the post processing steps.
- 'strip and ship'
    - Remove from platform
    - Remove support structures
    - Clean the part and the platform
    - Cure

Figure 4 Post-processing demonstration

Demonstration

- Remove the part from the platform
- Clean the part and platform
- Remove the support structures
- Return the Wash and Rinse tubs and cleaning area to their initial state (i.e. clean up the area)
- Cure the part

Exercises

None

Assignments

None

Lesson 13: Workflow Step 6: Inspect the Part

Goals

- Define inspection.
- Define metrology.
- Identify where inspection takes place in the process.
- Explain how to perform a part inspection and what to look for.
- Refer learners to Geomagic Control X for inspections in the future.
- Identify common print issues.

Objectives

- Define inspection and metrology.
- Identify where inspection takes place in the process.
- Explain how to perform a part inspection and what to look for.
- Identify common print issues.

Topics

Metrology and Inspections

- Define inspection and metrology.
- When it occurs; when to know when you need to do it
    - Strip and ship
    - Before/after post-processing, it depends (multiple points in process)
    - Usually after post-processing

Inspection Tools

- Scale Wizard
- Use a caliper
- Scanner
- CMM
- Height gauge

Common Print Issues

- Common print issues
    - Support related artifacts
    - Missing artifacts
    - Cause
    - How to (if possible) remedy each issue

    - Examples
- Geometry-related issues
    - Distorted/Print artifacts
    - Examples
    - How to (if possible) remedy each issue
    - Cause
    - Examples
- Guidelines / best practices
    - Not ideal for larger volume parts

Demonstration

- Visually inspect the part
- Use a caliper to take measurements
- Compare the measurements to the part requirements form and check tolerances

Exercises

- Inspect Several Parts. Report back to class on findings.

Assignments

None

LESSON 14: SECONDARY PROCESSES

GOALS

- Explain the difference between post-processing and secondary processing.
- Describe several common secondary processes for 3D printed parts.

OBJECTIVES

- Explain the difference between post-processing and secondary processing.
- Describe several common secondary processes for 3D printed parts.

TOPICS

DIFFERENCE BETWEEN POST-PROCESSING AND SECONDARY PROCESSES

- Standard, cleaned and cured (strip and ship; sand the support nubs and vapor hone – a few different terms and steps here)
- Secondary is additional

SECONDARY PROCESSES

- Plating
    - Definition – what is it? different ways to do it; ship to third party
    - What's important/unique about this process? What materials use this process?
    - An image that represents; clean, smooth parts
    - Example, where is it used?
- Painting
    - Definition – what is it?
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Joining
    - Definition – what is it? (gluing, resins, other ways)
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Assembly
    - Definition – what is it? checking tolerances for putting parts together
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Sanding and vapor honing

    - Definition – what is it? checking tolerances for putting parts together
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Bead blasting
    - Definition – what is it? checking tolerances for putting parts together
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Dyeing, SLS
    - Definition – what is it? checking tolerances for putting parts together
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?
- Milling (tapping, depends on the part)
    - Definition – what is it? checking tolerances for putting parts together
    - What's important/unique about this process? What materials use this process?
    - An image that represents
    - Example, where is it used?

Exercises

None

Assignments

None

LESSON 15: MAINTAINING AND TROUBLESHOOTING FIGURE 4 STANDALONE

The objective of this lesson is to teach the learner all the things they need to know about maintaining the printer, materials, and accessories. These learners are from a technical training institute and learn to operate various machines and machine tools. Learners should be trained and will be able to perform any and all maintenance tasks and change material. The idea is to get them trained to a point where they can be hired by a company and be held solely responsible to operate the Figure 4 3D printer. This includes part preparation in 3D Sprint, Figure 4 Standalone, maintenance and trouble shooting.

GOALS

- Demonstrate some of the basic maintenance on the Figure 4 Standalone.
- Identify the person to contact if there's an issue with the printer. Be aware of who that contact person is; either internally or externally.

OBJECTIVES

- Describe basic maintenance procedures for the Figure 4 Standalone.
- Use the user guide to locate various maintenance procedures.

TOPICS

DEMONSTRATION OF MAINTENANCE TASKS

- Tasks that are part of regular maintenance
    - Reload materials
    - Replace the filter (rarely done; check every 6 months; if you smell the material, time to change it)
- Tasks done after using the printer
    - Keep printer clean
    - Resin tray care – be careful
        - Stir material in tray prior to printing
        - Run a cleaning print
    - Clean platform; be careful picking it up, hard resin
    - Window for catch tray is clean
    - Projector lens clean (only if you have issues with the part and as needed)
- User guide, list of maintenance expected by customer – available to learners
    - Point out videos http://infocenter.3dsystems.com/figure4standalone/resin-tray-care
    - Resin tray care (expensive part) requires proper care
        - Moving it
        - Cleaning it
            - Paint filter to filter out debris
    - Running the clean print (extra precaution; if not sure if there was a prior failed print or issue before you print)
        - Membrane film

- Debris in resin

Troubleshooting

- What to do if it's not working – know who to contact, either someone in your own lab or 3D Systems
- Rarity of troubleshooting

Quiz Prep

- Identify topics that will be on the final quiz.

Exercises

None

Assignments

None

Lesson 16: Course Summary

Goals

- Summarize the key points.
- Review the 3D Printing Technician process.
- Prepare for the Final Project.

Objectives

- Summarize the key points of the course.
- Prepare for the Final Project.
- Prepare for the Final Quiz.

Topics

Prepare for Final Project

- Identify your lab date
- Review the workflow, the process, and whether you'll be working alone or with your partner

Quiz

- 20 questions

Exercises

None

Assignments

- Study for Final Quiz – Final Quiz delivered during last class, after labs. The Quiz has 20 questions. Learners are quizzed on these topics:
    - History of 3D Printing
    - AM technologies, processes, applications, industries
    - Material properties, reading material data sheets
    - Safety
    - Figure 4 Standalone and maintenance
    - 3D Sprint, geometries, and design terminology
    - Part orientation and supporting structures
    - Workflow
    - Processes

LESSON 17: FILE PREP LAB

EXERCISES

FILE PREP LAB

1. Steps 1-3
2. Submit to Instructor
3. Instructor approval

ASSIGNMENTS

- Study for Final Quiz – after labs. The Final Quiz has 20 questions. Learners will be quizzed on:
    - History of 3D Printing
    - AM technologies, processes, applications, industries
    - Material properties, reading material data sheets
    - Safety
    - Figure 4 Standalone and maintenance
    - 3D Sprint, geometries, and design terminology
    - Part orientation and supporting structures
    - Workflow
    - Processes

Lesson 18: Print Lab

Labs are scheduled and planned by the instructor. Learners can complete a final project by themselves or as a team. It is all at the discretion of the instructor. The parts can be left on the platform over night after printing, but most of the tasks should be performed together. For best results, have each learner or each team complete the project in one lab, from start to finish.

Learners should complete and submit the **Template - Quality Report.xlsx** form after their part inspection takes place.

Exercises

Print Lab

8. Send your part to the printer. Make sure the print job is in the queue.
9. Watch your part print for several minutes to make sure it starts correctly.
10. Inspect your part.
11. Complete and submit the **Template – Quality Report.xlsx** form after you complete your part inspection.
12. Post-process your part. Practice proper safety protocols.
13. Show your part to your instructor for grading and review.
14. Perform appropriate maintenance and cleaning on the printer, part, and lab area. Discuss what needs to be done with your instructor first, before you start.

Assignments

- Prepare your project report.

Lesson 19: Project Reports and Final Quiz

Objectives

1. Report on your project; challenges, process issues.
2. Complete the final quiz.

Topics

Project Reports

- Each team reports on their project, shows the part, and summarizes challenges they faced.

Exercises

- Project Reports

Final Quiz

20 Questions Covering Lessons 1-18. The questions and correct answers are shown here.

Print the separate file (**Final Quiz - Introduction to 3D Printing (Learners).docx or .pdf**) for learners to administer the quiz.

1. __C___ What is the first step in the 3D Printing Technician Workflow?
   - A. Import, examine, and repair the part file
   - B. Orient the part and create support structures
   - **C. Select/confirm the material and printer**
   - D. Print the part

2. __A___ What should you do if a particularly large amount of resin gets on your clothes?
   - **A. Remove the clothing immediately, and discard the clothing according to all local, state, and federal regulations**
   - B. Have your clothing dry cleaned as soon as possible
   - C. Immediately apply IPA to the spot to remove the resin
   - D. Put the clothing in your washing machine immediately and run it through the wash cycle at least twice

3. __D___ What should you do if print material comes in contact with your skin?
   - A. Apply heat to the affected area
   - B. Scrape it off with the Platform Scraper
   - C. Dip your skin into one of the tubs of IPA or use a paper towel to apply IPA to the affected area
   - **D. Wash your skin thoroughly with soap and cold water**

4. __D___ When is it safe to touch a printed part without wearing nitrile gloves?
   - A. After you remove the support structures
   - B. Once it has been cleaned in the appropriate solvent
   - C. When you are removing the part from the platform
   - **D. Once it has been properly cured**

5. __C___ What is a benefit of the Figure 4 Standalone printer?
   A. Large part file printing capabilities
   B. Labor-intensive post-processing to improve parts with poor surface quality
   C. Superior part resolution and surface quality
   D. It is a non-contact resin printer only specifically in the education vertical

6. __D___ Where is the material found during a print job?
   A. Catch tray
   B. Wash tub
   C. Mixing bin
   D. Print tray

7. __A___ Which manufacturing process is used by the Figure 4 Standalone printer?
   A. Vat Photopolymerization
   B. Powder Bed Fusion
   C. Binder Jetting
   D. Material Extrusion

8. __A___ Where should you look for information on the material properties of a particular material?
   A. Data Sheet
   B. Safety Data Sheet
   C. 3D Sprint User Guide
   D. Figure 4 Standalone User Guide

9. __A___ What is your main guideline for selecting a material and printer for a part request?
   A. Meeting the customer's part requirements
   B. Printing the part with the highest quality
   C. Using the material that the customer requested
   D. Making sure the part fits on the build platform

10. __B___ Which material property is the temperature at which a material deforms under a specified load?
   A. Shore D
   B. Heat Deflection Temperature
   C. Ignition Point
   D. Flash Point

11. __C___ When working in 3D Sprint, what does it mean if your part is outlined in red?
   A. The part does not need support structures
   B. You need to manually revise the units using the *Scaling by Unit* tool in the Prepare tab
   C. There is an issue with the part that should be resolved before printing
   D. The part is properly oriented and is ready to print

12. __A___ Which part orientation should you choose to optimize print speed?
   A. Minimize Z height
   B. Identify A/B sides and orient B down such that supports are on edges
   C. Stand geometry 'up'
   D. Limit the number of layers that print in curved geometries

13. __D___ What does “part orientation” mean?
    A. Generating objects on the platform in order to properly establish contact with all anchor points
    B. Measuring the part against the specifications and reporting on how the part meets the requirements
    C. The geometry of physical objects included in a part print job
    D. How you’re placing your part on the platform

14. __B___ Which component of a print job establishes contact and adheres to the platform?
    A. Drain Holes
    B. Support Structures
    C. Thick walls
    D. Curved Surfaces

15. __C___ Which priority should you have when selecting a material and printer for a part request?
    A. Printing the part with the highest quality
    B. Using the material that the customer requested
    C. Meeting the customer’s part requirements
    D. Making sure the part fits on the build platform

16. __D___ Which design consideration or best practice can help prevent trapped volume?
    A. Having smaller cross-sections
    B. Making the walls thicker
    C. Building extra support structures
    D. Inserting drain holes into the geometry

17. __B___ Which defect in a printed part is described as the visible/textural transition between build layers in the Z-axis?
    A. Void
    B. Stair-stepping
    C. Warping
    D. Delamination

18. __A___ After which process is a printed part safe to touch without nitrile gloves?
    A. Curing the part
    B. Cleaning the part
    C. Removing the part from the platform
    D. Removing the support structures from the part

19. __A___ Where would you find the required curing time for Figure 4 materials?
    A. Material Data Sheets
    B. Curing Oven User Guide
    C. 3D Sprint
    D. Figure 4 Standalone User Guide

20. __A___ Which task should you perform if any or all of your printed part drops into the resin tray?
    A. Run a Cleaning Job (clean print)
    B. Clean the platform in IPA
    C. Replace the resin tray with a new one (and new material)
    D. With gloved hands, use your fingers to feel in the resin tray for debris

End of Course Evaluations

Instructor Tasks

Please have learners to complete the course evaluation. The evaluation is their chance to provide feedback on the course and help us improve it for future learners. And as the instructor, we value your input. Please complete the instructor evaluation. Thank you!

1. Kindly ask learners to complete the **Course Evaluation for Learners**: http://3dsyste.ms/eval
2. Please complete the **Course Evaluation for Instructors**: http://3dsyste.ms/instructoreval