PUZZLE IT OUT

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Instructor Summary: *Puzzle It Out*

This document provides instructor guidelines for one of the ten integrated curriculum projects developed for the NSF-funded Necessary Skills Now (NSN) project (award #1501990). The NSN project partners consist of CORD and three national centers supported through the NSF's Advanced Technological Education (ATE) program: National Center for Systems Security and Information Assurance (CSSIA), Florida Advanced Technological Education Center (FLATE), and South Carolina Advanced Technological Education National Resource Center (SC ATE). The NSN project is designed to integrate employability skills into technical exercises, activities, and labs. The project partners created self-contained instructional modules vertically aligned to associate degree programs in **mechatronics/automation in manufacturing** and **cybersecurity in information technology**. (The activities described in this document support courses in manufacturing.) Six categories of employability skills, repeatedly mentioned in workforce surveys and research reports, served as the focus of the integrated curriculum:

skill category **1** TEAMWORK	*skill category* **2** PROBLEM SOLVING	*skill category* **3** VERBAL COMMUNICATION
skill category **4** WRITTEN COMMUNICATION	*skill category* **5** DEPENDABILITY/WORK ETHIC	*skill category* **6** PLANNING AND ORGANIZING

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Project Overview

Overall Purpose and Length

The purpose of the project described in this module is to incorporate employability skills (teamwork, problem solving, verbal and written communication, dependability/work ethic, and planning and organization) into activities relating to the development and execution of processes and procedures required to manufacture and assemble 6-piece burr puzzles. Project length will depend on availability of machines and the number of students.

Appropriate Course(s) for Implementation

Manual and/or CNC Milling

Blueprint Reading

Metrology

Introduction to Manufacturing Engineering

Manufacturing Quality

Introduction to LEAN Manufacturing

Optional:
SOLIDWORKS®
CAD, CAM software
3D Printer

Major Topics Addressed

- LEAN manufacturing
- Production processes and procedures
- Process development and execution
- Risk mitigation

Student Learning Objectives

Technical

- Students should be able to consistently machine puzzle pieces within specified tolerances.
- Students should be able to assemble the pieces into a finished product.
- Students should be able to complete an interference/slip-fit analysis and adjust tolerances and nominals for random fit application.
- Students should be able to develop realistic inspection plans based on function and tolerances of the puzzle pieces.

Teamwork

- Students should be able to work in a variety of team roles to manufacture and assemble 6-piece burr puzzles.

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- Students should create an environment of inclusiveness and diversity of ideas.
- Students should exhibit openness to ideas that differ from their own.
- Students should be able to manage conflict within and between teams.

Problem Solving

- Students should be able to analyze quality and/or process problems and develop corrective actions utilizing the *5 Why* methodology.
- Students should be able to develop, document, and execute reaction plans.

Verbal Communication

- Students should be able to provide and receive feedback and constructive criticism.
- Students should be able to describe the developed process and instruct others on how to execute the process.
- Students should provide status updates throughout the project development and execution phases.

Written Communication

- Students should be able to write Standard Work procedures.
- Students should be able to read and interpret Standard Work.
- Students should understand blueprints and assembly instructions.
- Students should develop documents describing lessons learned.
- Students should create and deliver wrap-up presentations.

Dependability/Work Ethic

- Students should be engaged with their teams.
- Students should be punctual in coming to class and returning from work and lunchbreaks.
- Students should alert their teams of plans to be absent.
- Students should demonstrate integrity by being accountable for their actions.
- Students should demonstrate responsibility and discipline in staying on task and producing assigned deliverables.

Planning and Organization

- Students should be able to develop the entire process for manufacture and assembly of a multipart project.
- Students should be able to allocate fixed assets (machines) and resources (people) to complete a project within a specified time limit.
- Students should be able to define and document the operational flow of material for a multipart project.
- Students should be able to develop the plans for material movement, segregation, tooling kits, and inspection “stations” for a multipart project.

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Equipment/Materials

- Manual milling machines equipped with DRO
- CNC milling machines
- Horizontal bandsaw
- Miscellaneous cutting tools
- Tape measure
- Flat file
- Production stops
- 0-6" calipers
- 0-1" and 1-2" Vernier micrometers
- 0-1" depth micrometer
- Optional
  - 0-1" drop indicator plunge indicator
  - Gage blocks (with end attachments, if possible)
  - Snap gages
- Aluminum
  - 1" x 1" or 7/8" x 7/8" (12 ft lengths)
  - 1" x 3" (saw into 1" pieces)

Discussion

Industry Scenario

Letter from the CEO:

As you may know, our overseas facility is shutting down. Because of our innovative work teams and proven track record of safety, quality, and on-time delivery, this plant will temporarily take over production of 6-piece burr puzzles.

Although the puzzle pieces are quite different from our other products, I am confident our employees will be able to develop and execute a capable, stable, and robust process for machining and assembling high-quality puzzles. We will introduce all employees to the manufacturing process and expect everyone to contribute 100% to the success of production. We have sales orders and commitments that we cannot afford to miss!

Our machinists and assembly technicians are currently assigned to another project, but your plant manager has told me of several improvement ideas coming from you recently. Therefore, the company directors are willing to give you the opportunity to demonstrate your creativity and project management skills in the process

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development and execution phase. Because of upcoming holiday orders, there is little time for delays or mistakes in retooling our production lines.

I see many benefits to this approach, as the production teams will be exposed to the "new product process," possibly injecting new ideas that yield time and cost savings. In addition, I anticipate that your work relationships with each other will grow stronger as you all work together to implement this process.

I look forward to a smooth and successful transition as we bring this work back to the USA.

Proposed Teaching Strategies

This project is divided into five main activities:

Activity 1: Getting It Right

Activity 2: Running Our Process

Activity 3: Test Runs

Activity 4: Launch of Machining and Assembly

Activity 5: Lessons Learned and Wrap-Up Presentations

Emphasize the employability skills students will use during the entirety of the project activities. The topics covered align well with teamwork, problem solving, written and verbal communication, planning and organization, and work ethic.

Adjust deadlines based on completion rates. The goal is for each student to have a working puzzle, the fruit of *working together*.

Activity 1: Getting It Right

During this phase of the project, review the following items:

1. Scenario, deliverables, and expectations
2. Phases of process development and execution
3. Blueprints and specifications for the puzzle
4. Machines, tools, and gages to be used (The students should compile a list.)

Activity Steps

1. **Scenario, deliverables, and expectations**

   The **scenario** serves as an authentic frame of reference that enables students to experience "real-world" situations in the manufacturing industry. Industry scenarios provide a link between academic activities and situations students will encounter in real-world manufacturing environments. You are encouraged to reinforce this scenario with local business examples, if available. Students can select their own company name for the project.

   The **deliverables** for the project are "X" number of completed puzzles (X determined by the number of students) that can be *randomly* assembled. As in the real world, there are time limits on planning, production, and assembly.

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The **expectations** are that students take on the roles of employees, engage in the project, acquire and apply technical and employability skills, and have fun. The student rubric for this project (3 Employee Performance Review.xlsx/pdf) is similar to real-world employee evaluations. Based on the listed technical and employability skill requirements, each student will be assessed on individual and team results. Share the employee performance review criteria with the class during Activity 1.

A link provided in the Faculty Resources section shows the history of the burr puzzle. You may wish to share the link with the class before proceeding with the other activity steps. Knowing the history of the product can make the finished puzzles a source of pride.

2. **Phases of process development and execution**

Briefly review the phases of development and execution of the plans to make the puzzles. The steps in this phase relate to *risk mitigation*. Our company does not have time for mistakes. Taking time up front to understand the product requirements will reduce the risk of issues in the production phase.

3. **Blueprints and specifications for the puzzle**

Distribute blueprints of the (6) piece-parts and assembled puzzle to each student (4 Six-Piece Burr Puzzle.pdf/pptx).

Discuss **fit, form, and function** requirements of the puzzle. The deliverable requirements stipulate that **the puzzles must assemble with slip fits and all pieces must be interchangeable**. This is a common requirement in real-world manufacturing. Unintended interference fits will affect assembly. Issues discovered at assembly can result in missed ship dates, unplanned material replenishment due to scrap or rework, overtime, and low morale. Our tight schedule does not include time to replenish material or rework parts found to be "nonconforming" at assembly. Traditional teaching methods allow the students to tweak the parts until they successfully assemble. This exercise elevates that expectation: **parts must work the first time**.

Optional. If CAD files were created or SOLIDWORKS® drawings are being used, update and distribute prints with new nominals and tolerances and save as a revision-level change.

Optional. Assign a team to create CAD files from the PDF files. If CNC mills are selected for machining, CAM files can be created from the CAD files.

Optional. Assign a team to create a 3D printed model from the provided SOLIDWORKS® files (10 Solidworks Part and Assembly Models.zip) to assist with process development.

4. **Machines, tools, and gages to be used**

Instruct the students to generate lists of all the machines, tools, and gages to be used in Activity 2. To carry out the activity, students must know what tools they have, how many of each they have, and what each tool's capabilities are. Ask students to consider back-up tooling plans as they generate the lists. If a tool breaks, a plan to replace it should be ready to keep the process moving. Assign student teams to work on these lists.

Optional. Have a student who is proficient with word processing or spreadsheet software create the lists as teams provide information.

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Activity 2: Running Our Process

This phase of the project consists of the following activity steps:

1. Discuss LEAN manufacturing
2. Develop the overall process
3. Assign teams
4. Develop processes

Activity Steps

1. **Discuss LEAN manufacturing**

   LEAN manufacturing is an important part of this project. Most companies have implemented procedures supporting LEAN principles, and they expect employees to adhere. If the students understand the topics shown below, the process will be more efficient and will produce higher-quality parts. Cover these topics before the students develop their processes:

   – Wastes of LEAN

   – Standard Work (process steps)

2. **Develop the overall process**

   Using the generated lists of machines, lead the students through a discussion in which they select machines to be used in processing the parts. Each student should be encouraged to voice opinions and suggest options. Stress the importance of listening before speaking and being open to other people's ideas. This is the brainstorming phase; all ideas are encouraged. This is also the phase where minor conflicts can arise. Because the scenario requires getting the process up and running quickly, the students will be under pressure, just as they would be in the workplace. The purpose of this exercise is twofold: to develop a map of the general process and to build good communication skills.

3. **Assign teams**

   Assign members of the class to teams. The teams will develop the machining processes for the parts. In the workplace, companies expect employees to work well within their teams and to support the overall goals of their employers. Workers are typically *assigned* to teams – they don't usually get to pick their teams. Preparing students to practice teamwork skills is essential for their success. Facilitate "team icebreakers," for example, in which students share something about their hobbies, interests, and experiences that the other students may not know.

   Optional. Assign students or teams to roles such as assembly, logistics, supervision, engineering, and quality.

   Optional. To the extent possible, make the teams diverse with respect to gender, race, physical appearance, socioeconomic status, and other differences.

4. **Develop the process**

   Assign your machining teams piece-parts for production process development. Encourage each team to be creative in processing the parts and to communicate with the other teams. You may opt to put a time limit

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on this exercise. The deliverables for this exercise are 1) the draft process steps and 2) demonstrated success in collaboratively producing a part. If you created other teams (for assembly, quality assurance, etc.), they should also develop tasks and document how the tasks will be performed.

Optional. If a team is using a CNC, the program can replace the machining portion of the process steps.

Activity 3: Test Runs

This phase of the project consists of the following activity steps:

1. Review expectations of trial-and-error test runs
2. Test and validate developed processes

Activity Steps

1. **Review expectations of trial-and-error test runs**

   In trial-and-error test runs in manufacturing, design and manufacturing engineers work together to determine whether machines, fixtures, tooling, and gages are *capable* of producing a product. Our CEO has asked our machinists to be a part of this development. Anything goes in the first round of trial cuts, but the teams must have documented steps from which to work. You can limit the number of test pieces based on the availability of raw material.

   Optional. Have "blanks" machined as a class project prior to this activity. Doing so will replicate receiving material ready for machining (as in the workplace) versus the traditional method of sizing material.

2. **Test and validate developed processes**

   Direct the students to test and validate their developed processes on their assigned machine(s) and update the overall process flow as needed. Students should record "lessons learned" for incorporation into the second draft of their process steps. Direct the students to run another trial using the improved process. The expectation is that the process will be "set" after this second run. Stress the importance of time management and attention to detail.

   After the trial runs have been completed, lead a discussion on what went well and what didn't. Each team should have taken note of "lessons learned" from this stage of the project. Understanding what does not work saves time in future product development.

Activity 4: Launch of Machining and Assembly

This phase of the project consists of the following activity steps:

1. Review expectations for production
2. Devise a plan for managing nonconforming material and review *5 Why* problem solving
3. Switch teams to new processes

Activity Steps

1. **Review expectations for production**

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Each team has had time to develop and validate the process. (They were given a degree of freedom that is not allowed in the workplace.) One of our deliverables consists of parts made correctly the first time. To ensure the integrity of the process, discuss why following process steps is critical. Deviating from the process, without team discussion and approval, goes against our company values. In the workplace, deviating from a defined process may result in termination of employment.

You should have the class decide what the "work day" looks like. A morning (start of class) start-up meeting is required to set the goals for the day. A daily wrap-up meeting should cover goals met, goals not met, and a plan for getting back on track. Does the class want to adjust break schedules to keep the spindles turning? How will tardiness or unexcused absences be addressed? This exercise helps set the rhythm and expectations of the "shop."

Optional. If you assigned a student to act as supervisor, that student should facilitate these meetings.

2. **Devise a plan for managing nonconforming material and review *5 Why* problem solving**

   Manufacturing companies should always take precautions to ensure that substandard parts do not get into inventory. Lead a discussion of the internal and customer impacts of nonconforming material. Lead the students in developing a plan for quarantining and dispositioning (scrapping, reworking, or deviating) their nonconforming material.

   Our company utilizes the *5 Why* methodology for problem solving. Making mistakes is inevitable, but repeating mistakes is unacceptable. We use *5 Why* to learn why something went wrong and to put in place measures that mitigate the risk of reoccurrence. Lead the students in exercises using the *5 Why* methodology so they are familiar with the process before they need to use it. Ensure that students play both roles in the *5 Why* scenarios.

3. **Switch teams to new processes**

   Remind teams of the time and effort it has taken to get to this phase. Because of their dedication and hard work in developing their processes, they are now ready to begin a production run—with one adjustment. You will mix up the teams so that each student is running a process that he or she did not help to develop. In the workplace, employees must be able to adapt to sudden changes. Switching team members will expose students to this reality, as well as give them an opportunity to practice their verbal and written communication skills as they cross-train others on their developed processes. Once the students have completed the cross-training, each team should "sign off," indicating that its members are trained and ready to run the process.

   Optional. You may elect not to hold the teams to strict "cycle times" but instead to a general completion time and date. Adjust this as needed, but call for discussion if times keep dragging out longer and longer: What is happening in the process?

Activity 5: Lessons Learned and Wrap-Up Presentations

This phase of the project consists of the following activity steps:

1. Discuss lessons learned and review the *5 Whys* of the problems encountered
2. Students make wrap-up presentations

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Activity Steps

1. **Discuss lessons learned and review the *5 Whys* of the problems encountered**

   Facilitate a discussion of aspects of the process flow that did and did not go well. Ask the students what they would do differently if they had the opportunity. Review all nonconforming product reports for similarities in failure modes. What preventions could be put in place to mitigate mistakes in the future? The students will use this information for their presentations.

2. **Students make wrap-up presentations**

   Assign each team the task of creating and presenting a PowerPoint presentation on the major steps of the project. Choose topics based on your class results. If students struggled with teamwork, their presentations should address how teamwork (or lack thereof) affected their results. Each team member should speak in front of the class. (As employees they will probably be expected to speak in front of coworkers and managers.)

Student Activities

Activity 1: Getting It Right

- Review the scenario and decide on a company name.
- Read the employee performance review (3 Employee Performance Review.xlxs/pdf), which describes a way to measure how well you contribute to the company's success.
- Review the blueprints of the puzzle pieces and assembly (4 Six-Piece Burr Puzzle.pptx/pdf).
- Develop a plan to have your set of prints readily available.
- List impacts on the plant and customer when interference fits and select fits are found at assembly.
- Update drawings with revised nominal(s) and tolerances.
- With your assigned team, generate a list of machines, tools, and/or gages.
- Document machine tool capability.

Activity 2: Running Our Process

- This is an opportunity to provide feedback to "engineering." Based on your machining experience, list the waste(s) you see as a potential concern.
- Our company values Standard Work. Explain how not following Standard Work can affect our ability to meet the deliverables of the puzzle project.
- The class (as a team) develops a general process flow map depicting material flow through the shop.
  - The map can be created on a whiteboard, sticky notes, PowerPoint, or Visio.
  - Use the list created in Activity 1.
- Students select a team name.
- Students share one thing their teammates do not know about them.

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- As a team, decide how you will machine/assemble your assigned part or complete your process.
- Fill out the process sheet with basic information including how to inspect the part.

Activity 3: Test Runs

- Assign roles within your team to validate your process.
- Complete your assigned part/process trial runs using your process sheet(s).
- Update team process sheet(s) based on results of the trial runs.
- Discuss things that went well and how you could improve on things that did not go as planned. Be prepared for class discussion on this topic.

Activity 4: Launch of Machining and Assembly

- As an entire class "team," develop and document a plan for nonconforming material.
- Develop meeting/break schedules and assign an "employee" to take notes for follow-up.
- Complete the assigned *5 Why* exercises (5 Five-Why Exercises.pptx/pdf).
- Train the team assigned to execute your process.
  - Have the "new" team members sign off, indicating that they are trained and prepared to run the process.
- Machine and assemble the puzzles in the time allotted.
- Complete *5 Why* analysis for all nonconforming parts.

Activity 5: Lessons Learned and Wrap-Up Presentations

- Within your team, create a PowerPoint presentation citing what went "as planned" and what did not. Each team member should present at least one item in front of the class.
- Your team should practice the presentation.

Faculty Resources

Background Material

- Students must be familiar with machine shop safety protocols.
- Students must have hands-on milling experience.
- Students must know how to read blueprints.
- Students must know how to use calipers, micrometers, and indicators.
- A completed puzzle (alum or 3D printed) will greatly improve the ability to plan the process.
- Machining a puzzle ahead of time will help to anticipate potential failure modes.
- Students may struggle in assembling the puzzle. Have printed solutions available so they can practice outside of class.

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- Students may be apprehensive (or even phobic) about presenting in front of the class. Be prepared to assist in alleviating this fear.

Handouts and Supplemental Materials

- 2 Wrap-Up template.pptx/pdf
- 3 Employee Performance Review (xlsx/pdf)
- 4 Six-Piece Burr Puzzle (pptx/pdf)
- 5 Five-Why Exercises (pptx/pdf)
- 6 Process Steps Templates with Examples (xlsx/pdf)
- 7 LEAN 8 Wastes and Standard Work Instructions (pptx/pdf)
- 8 Puzzle Solution from 3D Model Images (pptx/pdf)
- 9 3D Printer Files.zip (contains STL files)
- 10 Solidworks Part and Assembly Models.zip (contains SLDPRT files)
- 11 3D Model Images. zip (contains JPG files)

Suggested Websites

Burr Puzzle Info: https://www.artofplay.com/blogs/articles/history-of-the-burr-puzzle

Fear of Public Speaking
https://www.mayoclinic.org/diseases-conditions/specific-phobias/expert-answers/fear-of-public-speaking/faq-20058416

5 Why Methodology: https://www.mindtools.com/pages/article/newTMC_5W.htm

Assessment

See 3 Employee Performance Review (xlsx/pdf) for suggested measures and a printable template, including the following dimensions for assessment:

- Communication
- Dependability
- Planning and organization
- Problem solving
- Safety
- Teamwork
- Technical
- Work ethic
- Constructive and destructive behaviors

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