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Designing a Series of Activities to Expose High School Students to Manufacturing

Mr. Yury Alexandrovich Kuleshov, Purdue University

Yury A. Kuleshov is a graduate student earning his Ph.D. in Technology degree from Purdue University, West Lafayette, Indiana. He received his Diploma in Engineering (6-year program) from Bauman Moscow State Technical University, where he majored in Robots and Robotic Systems, and specifically Underwater Robots and Vehicles, and his M.S. in Engineering Technology degree from Purdue University. He has experience working as an engineer, a research and teaching assistant, and an instructor. His research as a Ph.D. student is in autonomous vehicles, cybersecurity, engineering education, and K-12 education.

Dr. Anne M Lucietto, Purdue University

Dr. Lucietto has focused her research in engineering technology education and the understanding of engineering technology students. She teaches in an active learning style which engages and develops practical skills in the students. Currently she is exploring student choices.

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Abstract

High schools across the United States expose students to various types of engineering curriculum, including activities of different duration and content. The duration varies from 30 min to a class-long and beyond, going into a series of class meetings to finish an activity. A lot of content is focused on the school subject topics. Some of those subjects, like mathematics, physics, and chemistry are present in both high school and college. Others, like some types of engineering, have no direct link to the school subjects. One example is manufacturing engineering and manufacturing engineering technology. When students are unaware of the manufacturing possibilities, they end up selecting the different career paths, which is the negative scenario for the United States domestic manufacturing efforts.

The authors designed a series of high school activities that would introduce students to the topics of Smart Manufacturing and Industry 4.0 (I4.0). The goals of the activities are to a) raise student awareness and stimulate interest in the topics and b) inspire students to pursue a degree in a new manufacturing-related college major at a Midwestern university. The authors collected information on the existing activities from different sources, such as the Society of Women Engineers (SWE) website, different professional education websites of the top engineering universities in the United States, and others. The authors worked with the leadership from the Midwestern university's academia-industry collaboration center and select manufacturing industry stakeholders to retrieve additional activities.

The content of the activities can provide students with the knowledge and skills that are essential for them to have in the 21st century economy. The designed activities can be useful for both the practitioners in the field and higher education institutions, who seek to inspire and recruit future talents to underrepresented fields like manufacturing. The structure of the designed activities can be used to design additional activities and align them with appropriate I4.0 competencies. The potential deployment of the activities in high school classrooms will help meet the United States strategic goal of supporting domestic manufacturing efforts and raising its competitiveness on the world market.

Keywords: Manufacturing, Smart Manufacturing, Machine Learning (ML), Artificial Intelligence (AI), Industry 4.0 (I4.0), Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), Cost-Benefit Analysis, Lean Manufacturing, Data Analytics, K-12, Undergraduate, Engineering, Engineering Technology, STEM

Introduction

High schools across the United States expose students to various types of engineering curriculum, including activities of different duration and content. The duration varies from 30 min to a class-long and beyond, going into a series of class meetings to finish an activity. A lot of content is focused on the school subject topics. Some of those subjects, like mathematics, physics, and chemistry are present in both high school and college. Others, like some types of engineering, have no direct link to the school subjects. One example is manufacturing engineering and manufacturing engineering technology. When students are unaware of the manufacturing possibilities, they end up selecting the different career paths, which is the negative scenario for the United States domestic manufacturing efforts. Furthermore, the ongoing new industrial revolution takes the society to the Industry 4.0 (I4.0) reality, which will eventually transform all aspects of the life of the society, including education.

This paper provides a literature review on the current efforts from educators and education researchers to bring I4.0 to Pre-K classrooms. The authors identified the gaps and concluded on what is being and can be done to address those gaps. The authors then presented their ongoing effort to provide I4.0-related activities to high school students. The authors discussed the successes and challenges in developing the activities. The authors provided a description of the future development of the project.

Literature Review

Current Pre-K students is an integral part of the society, who will be entering the workforce in the next two decades must be ready for the challenges of I4.0. The education needs to be transformed to facilitate student adaptation to I4.0 [1, 2]. The competitive environment of the current world economy and specifically the economical advances of the Global South. require a mutual effort from the country's educators, education researchers, and policymakers to bring I4.0 transformation to educational institutions. Global South includes the countries to the south of the Western democracies that used to be referred to as Third World countries, many of which were previously colonized [3]. Select countries of the Global South have made significant progress in building knowledge-based, innovative economies, and, for example, routinely use such technologies as Artificial Intelligence (AI) [4]. The integration of AI-based solutions in both academia and industry is essential for the ongoing I4.0 transformation.

Some higher educational institutions in the country have already made major steps in making I4.0 a part of their curriculum [5, 6]. The Pre-K level curriculum if far from seeing I4.0 concepts in all their complexity as everyday routine. For example, the existing federally accepted educational standards do not even have a single reference to I4.0 [7]. The nine I4.0 competencies are the following: Autonomous Robot, Simulation & Augmented Reality, Horizontal & Vertical Integration, Industrial Internet of Things (IIoT), Cybersecurity, Cloud, Additive Manufacturing, Supply Chain, Big Data Analytics [8]. Certain Pre-K educational institutions make individual efforts in addressing at least some of the nine core pillars of technological advancement or I4.0 competencies [9, 10]. Some of the competencies are being addressed at Pre-K institutions but are not directly referred to as I4.0 competencies and not positioned to form a 21st century manufacturing mindset among students. For example, Simulation & Augmented reality are the most popular, and Cybersecurity and Cloud are the least popular. The entire breakout of the popularity of the activities retrieved from a national online K-12 STEM activity repository [11] is presented in Figure 1.

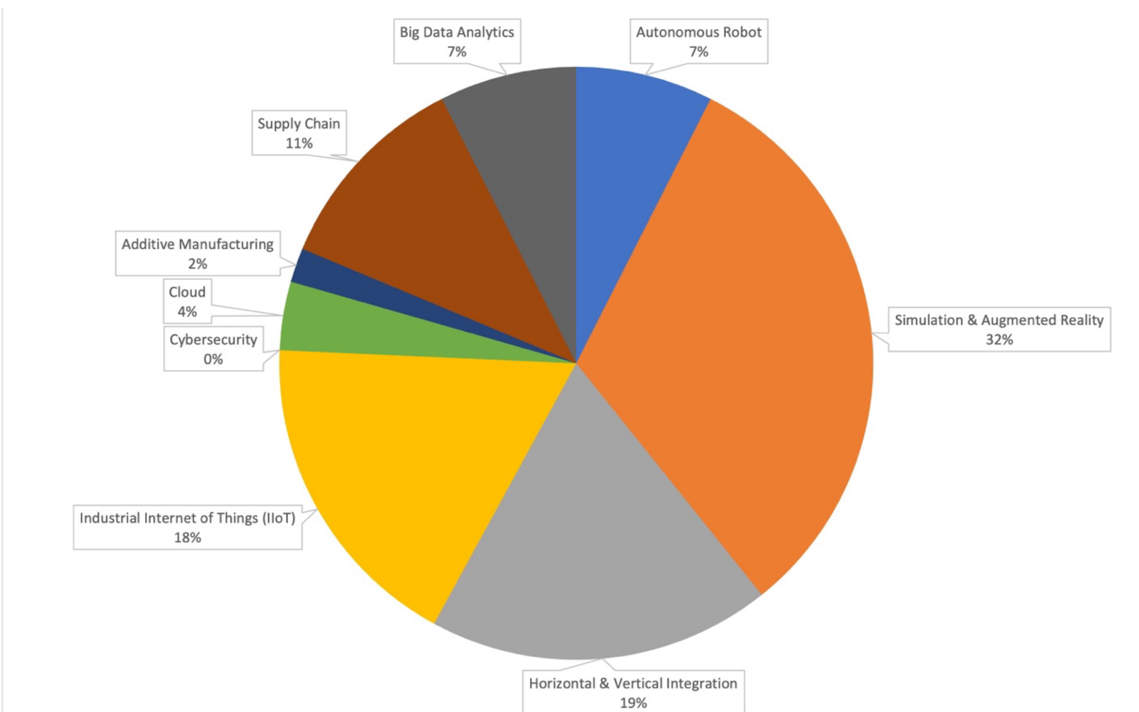

Figure 1. Distribution of I4.0 Competencies among Retrieved I4.0-Related Activities

The initial search among over 1100 K-12 STEM activities returned 70 results with the keyword “manufacturing.” Importantly, I4.0 was not present in the description of all of those activities. The authors proceeded with I4.0 competency coding basing on the content of the activities. The limitation is the choice of the repository. The selected repository is a National Science Foundation (NSF)-funded project with over 50 contributing academic institutions, which adds to the credibility of the author's choice. At the same time, other repositories or additional sources may return the results different from the received results. For example, the topic of Additive Manufacturing, which constituted only two percent of the retrieved manufacturing-related activities has been popular among K-12 educators for at least a decade, at the emergence of three-dimensional (3D) printing era [10]. Such printers became a necessity in makerspaces and as one of the first I4.0-related activities in K-12 settings. Some authors are now trying to link makerspaces to the advancement of manufacturing in I4.0 settings [12].

Another discovery is the discipline orientation of the authors who write about both STEM education, including Manufacturing and I4.0. The majority of the retrieved articles came from the industry (manufacturing), business and economy-oriented journals. One should not be surprised to observe such a pattern. Academia and industry have a long story of differences in understanding the needs of the graduates [2, 13]. Academia's traditional focus on subjects and the continuous effort to use those to build real-life skills in students comes in conflict with industry's orientation towards specific problems and economic goals. Academia's ongoing transition towards problem-based learning and implementation of backwards curriculum design have been improving the situation in the last decade. Still, the harmonization of skillsets between academia and industry is yet to happen. This is especially true for K-12, where curriculum is restricted by standards more than at any other academic level. Moreover, standards must come through a significant number of iterations prior to being implemented. The organizations, who develop national K-12 STEM standards need to work with industry and policymakers to introduce I4.0 competencies to K-12 students.

Additional discovery is the international origin of the retrieved articles. Moreover, a lot of retrieved articles originated in Global South [1, 9, 14, 15]. While international authors use the I4.0 frameworks different from the nine pillars of I4.0, they agree on the critical importance of I4.0 competencies among both K-12 students and teachers.

Multiple authors mention "Education 4.0", defined as a transformed, personalized education in I4.0 environment [14, 16]. The discussion of Education 4.0 is a product of I4.0 transformation but would be out of scope of the current review of the literature.

The following is the description of the four activities that the authors designed to boost interest in manufacturing among high students in a Midwestern state and to potentially prepare them to enter the newly introduced I4.0 undergraduate program.

Methodology

The authors designed a series of high school activities that would introduce students to the topics of Smart Manufacturing and Industry 4.0 (I4.0). The goals of the activities are to a) raise student awareness and stimulate interest in the topics and b) inspire students to pursue a degree in a new manufacturing-related college major at a Midwestern university. The authors collected data from different sources, such as the Society of Women Engineers (SWE) website [17], different professional education websites of the top engineering universities in the United States, and others. The authors worked with the leadership from the Midwestern university's academia-industry collaboration center and select manufacturing industry stakeholders to collect additional data. The activities can be deployed in the select local high school classrooms.

Select Experiences of Authors to Support Work and other Considerations

Designing and implementing effective outreach activities is a multifaceted endeavor that requires careful planning and consideration of various factors. Authors across different disciplines have highlighted the importance of outreach initiatives in engaging diverse audiences and achieving specific goals. For instance, Kent [18] discussed how outreach activities can serve to align individual memories with an official version of the past, emphasizing the role of these activities in shaping collective narratives. Laursen, et al. [19] focused on the societal impact of short-duration science outreach interventions, aiming to enhance science literacy and diversify the science workforce. Similarly, Aslam, et al. [20] pointed out that outreach activities offer valuable opportunities for teachers to interact with leading scientists and stay abreast of cutting-edge research, thereby enhancing their professional development. Moreover, the design of outreach programs is crucial for their success. McCauley, et al. [21] highlighted the benefits of constructivist approaches in science outreach, emphasizing the importance of active and creative learning experiences for students. Additionally, Dr. Lucietto (an author) lead the design for middle school students, providing insights into the planning and execution of such outreach initiatives [22], and Kuleshov (an author) volunteered to lead the sessions as an engineering and technology professional with background in both academia and industry. Pluth, et al. [23] underscored the significance of collaboration and near-peer mentoring in sustainable science education outreach, emphasizing the need to connect outreach topics to real-world experiences to spark interest and engagement among participants. In conclusion, the literature reviewed underscored the diverse objectives and methodologies employed in designing and implementing outreach activities across various fields. By incorporating innovative approaches, fostering collaborations, and aligning activities with the interests of target audiences, outreach initiatives can effectively promote learning, engagement, and knowledge dissemination within communities.

Description of the Activities

The authors selected four topics at the intersection of engineering, engineering technology, and manufacturing and put them in the I4.0 settings. The selected topics are the following:

1. Computer Aided Design, Manufacturing, & Engineering (CAD/CAM/CAE) X Industry 4.0
2. Cost-Benefit Analysis X Industry 4.0: Solar Energy Case
3. Lean Manufacturing X Industry 4.0
4. Data Analytics X Industry 4.0: Evaporation Case

These topics align with the programmatic goals set forth by the competencies of I4.0. The topics match select competencies of I4.0 as shown in Appendix A.

Each activity consists of the following basic documents:

- A One-Pager Document, to provide general *summary* of the activity, *I4.0 connection*, and *learning objectives* for students, their parents, and teachers
- Teacher Manual
- Student Manual
- Student Worksheet

See Appendix B for examples of the activity and provided documentation for conducting the exercise, information for the teacher and student(s), including a student worksheet. These materials were prepared with teachers, parents, and school audiences in mind as they may all want to consider using them to support manufacturing learning in and out of the classroom.

The activity drafts are available online to facilitate the distribution of materials as they relate to manufacturing. These activities are available online for *all* teachers across the country. Hence, the authors are not limiting their initiative by one community or state and encourage everyone to use those for the benefit of the nation’s attitude towards the revival of manufacturing at the I4.0 level.

Development of the Example Materials

In the context of I4.0 systems, educational initiatives are increasingly integrating activities that align with the goals of manufacturing processes. These initiatives mirror the principles and aims of I4.0 technologies, providing students with practical insights into the application of advanced manufacturing concepts. Bhatia and Kumar [24] highlighted how stakeholder and competitive pressures towards sustainability can drive organizations to adopt I4.0 technologies, leading to improved performance outcomes. This connection can be conveyed to students through activities emphasizing sustainability and efficiency in modern manufacturing practices. Additionally, Ang, et al. [25] emphasized the importance of energy-efficient smart design and operation in an I4.0 environment. They suggest that activities focusing on optimizing energy usage and intelligent manufacturing processes can help students understand the role of technology in enhancing sustainability within manufacturing systems. Engaging students in activities that promote energy efficiency, smart design, and operational intelligence can effectively communicate the goals and benefits of I4.0 systems, preparing the next generation of professionals to contribute to the evolution of manufacturing practices towards more sustainable and efficient operations.

In particular, the Data Analytics X Industry 4.0: Evaporation Case provides students with an example of how a simple physical phenomenon of evaporation can be utilized in I4.0 environment of a modern manufacturing facility. Select parts of the activity were adapted from TeachEngineering [11]

Data analytics plays a significant role in I4.0 systems, particularly in applications related to industrial processes like evaporation. Chen and Wang [26] proposed a hybrid approach that integrates big data analytics and I4.0 principles to project cycle time ranges, offering a unique method different from traditional approaches. Additionally, Hinojosa-Palafox, et al. [27] presented an analytics environment architecture designed for industrial cyber-physical systems, outlining essential analytics components for data processing and interpretation within an I4.0 context. These studies highlight how the combination of data analytics and I4.0 can provide valuable insights into industrial processes by utilizing advanced technologies to optimize operations, enhance efficiency, and foster innovation in manufacturing settings. The application of data analytics within an I4.0 framework enables organizations to gain a competitive advantage by leveraging data for informed decision-making and improved overall performance.

Discussion/Conclusion

Based on the literature review, it is evident that the absence of unified terminology related to I4.0 in education, especially STEM, makes it challenging to locate relevant literature on the subject. This lack of standardization can also make it difficult for teachers and schools who aim to introduce I4.0 and its manufacturing component to K-12 students. Therefore, it is crucial to involve additional stakeholders such as industry representatives in developing standards for K-12 STEM curricula.

The activities designed for students should impart knowledge and skills that are essential for the 21st century economy. The authors' experience in designing such activities can be beneficial for both practitioners and higher education institutions seeking to inspire and recruit future talents to underrepresented fields like manufacturing. Deploying these activities in high school classrooms can contribute to the strategic goal of supporting domestic manufacturing efforts and enhancing the competitiveness of the United States in the global market.

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Appendix A

Topic Alignment Table

Table 1

#	Activity / I4.0 Competency .	Autonomous Robot	Simulation & Augmented Reality	Horizontal & Vertical Integration	Industrial Internet of Things (IIoT)	Cybersecurity	Cloud	Additive Manufacturing	Supply Chain	Big Data Analytics
1	CAD-CAM-CAE X I4.0	0	1	0	0	0	1	1	0	0
2	Cost-Benefit Analysis X I4.0	0	1	1	0	0	1	0	1	0
3	Lean X I4.0	0	1	1	1	0	1	0	0	0
4	Data Analytics X I4.0	0	1	0	1	0	1	0	0	1

Appendix A

Detailed Description of Topic Alignment

1. **Computer Aided Design, Manufacturing, & Engineering (CAD/CAM/CAE) X Industry 4.0**

Orthographic projection, a technique used in spatial visualization, is an essential skill for engineers. Among other things, an engineer's work involves generating an idea and communicating it clearly to fellow engineers and company management. Some ideas eventually become products that find their way to the market. Orthographic drawings are used for detailing the product designs for manufacturing. Orthographic drawings show an object (product) from multiple viewpoints and facilitate prototyping and eventually production. Isometric drawings provide a three-dimensional view of an object and can help others visualize an idea prior to prototyping. Orthographic and isometric drawings need to be done to a country or company's standard for other engineers to understand them. Engineers would normally use computer aided design, manufacturing, and manufacturing (CAD/CAM/CAE) computer applications to draw the product parts and assemblies. Then the drawings would be loaded to the machines that "read" them and produce the product. The new challenges to the economy and current world trends require the upgrade of existing manufacturing processes to the new I4.0 environment for the companies to stay competitive on the world market. Cyber-physical systems of I4.0 provide expanded opportunities for the application of CAD/CAM/CAE. Smart Manufacturing is the new reality, where computer and automation technologies are brought to a new level of synergy. For example, Additive Manufacturing allows to prototype and manufacture the parts on site. Previously, companies would need to use outside sources for select types of products and materials. Additive Manufacturing shop integrated in a Smart Manufacturing factory has a potential to significantly reduce the time between the idea and its implementation. I4.0 environment provides for continuous product improvement with the real-time input from engineers and consumers.

2. **Cost-Benefit Analysis X Industry 4.0: Solar Energy Case**

The elements of the conventional cost-benefit analysis are an integral part of I4.0 environment, including manufacturing. A cost-benefit analysis is an industry proven methodology to assess and compare the strengths and weaknesses of a project to further decide on the project implementation. Cost-benefit analysis has been one of the essential tools for United States for over two decades. The new challenges to the economy and current world trends require the integration of proven techniques, such as cost-benefit analysis, in the new I4.0 environment for the companies to stay competitive on the world market. Cyber-physical systems of I4.0 provide expanded opportunities for the application of cost-benefit analysis techniques in manufacturing. Smart Manufacturing is the new reality, where computer and automation technologies are brought to a new level of synergy. For example, a company can create a *digital twin* of a manufacturing process and simulate different implementation scenarios for performance. A digital twin is a computer model, which has the qualities of a real product or process that are critical for their description as related to select outside actors. The digital twin of a solar energy farm and the consecutive simulation can significantly contribute to a company's decision to build a solar energy farm at a specific location (industrial park, factory, etc.) and potentially prevent the company from losing money. The application of the elements of cost-benefit analysis to the design of processes at/for a new Smart Manufacturing factory will allow a company to achieve the balance between the essential need for profitability and the sustainability agenda driven by the community and government.

3. Lean Manufacturing X Industry 4.0

The application of Lean principles to I4.0 environment is an emerging practice that is just starting to transform the manufacturing world. The ultimate idea behind Lean is the elimination of the non-value-added components or "waste" from any process, including manufacturing processes. Lean has been an essential tool for United States companies to compete against the developing economies for over two decades. The new challenges to the economy and current world trends require the integration of proven principles, such as Lean, in the new I4.0 environment for the companies to stay competitive on the world market. Cyber-physical systems of I4.0 provide expanded opportunities for the application of Lean principles in manufacturing. Smart Manufacturing is the new reality, where computer and automation technologies are brought to a new level of synergy. For example, modern devices, such as industrial sensors, can "talk" to each other, and computers will process enormous amount of sensor data, and use this data to model optimal manufacturing processes or predict product failures. Industrial computers have a much higher level of autonomy compared to the previous generation machines, which involves the rapidly growing machine learning and artificial intelligence (AI) technologies. Lean deployment to a new Smart Manufacturing factory will allow to use the new tools to achieve an essential goal of meeting customer expectations ("product") at the lowest possible cost (reduce "waste").

4. Data Analytics X Industry 4.0: Evaporation Case

Reducing drying times and the amount of materials used is an important *optimization* problem in engineering and manufacturing. Paint, liquid adhesives, and other liquid materials for machine manufacturing and building construction must cure, harden, or dry as a part of many multi-step manufacturing processes. Carefully prepared drying time estimates help to optimize the manufacturing processes. The new challenges to the economy and current world trends require the upgrade of existing manufacturing processes to the new I4.0 environment for the companies to stay competitive on the world market. Cyber-physical systems of I4.0 provide expanded opportunities for the application of drying time estimates in manufacturing. Smart Manufacturing is the new reality, where computer and automation technologies are brought to a new level of synergy. For example, drying time data could be continuously uploaded to Cloud and processed accordingly (i.e., evaluation, estimation). The production equipment at a Smart Manufacturing factory would automatically adjust painting process based on the input from the specific paint batch in the specific steps of the process in given conditions during a given timeframe. As a result, the company, owning the factory, would have an optimized, self-regulating *dynamic* process, with decreased resource (paint) use and reduced production (painting) time. Smart Manufacturing factory will allow the company to achieve the balance between the essential need for profitability and the sustainability agenda driven by the community and government.

Appendix B

Sample Activity

DATA ANALYTICS X INDUSTRY 4.0: EVAPORATION CASE

Teacher Manual

1. Pre-Req Knowledge

Students should have basic knowledge of:

- Physics (for example, the evaporation process; and have experience using lab scales),
- Geometry (for example, dimensional analysis),
- Geography/Economy (for example, why supplies/materials management considerations are important in the economy (renewable and non-renewable natural resources); and how natural resources can be sustainably used),
- Manufacturing (for example, the types of people involved and their roles; what manufacturing does to create a product; and how it can be improved by evaluating current process).

2. Introduction/Motivation

Try yourself in a role of engineers and assist a local manufacturing facility that designs and manufactures mining truck engines. Part of the facility's process requires finishing their produced engines with paint. This process requires the use of as little paint as possible and to achieve a fast-drying time, spend less paint, and, at the same time, keep the paint surface quality within the corporate standards. As engineers, you will work in groups to 1) calculate the drying time, 2) design an optimal container to capture water from a spray container. By building this container, you will then be able estimate the amount of time it takes for your projects at the sports equipment facility to dry.

Other considerations:

If you were to take a glass of water, weigh it, place it on a desk, and leave it for 24 hours, what would happen? We know that the water in the glass, if left for a long period of time, would eventually evaporate. However, what if we wanted to find out how much water evaporated in a day? Would you be able to make any qualitative observations about the water? What about quantitative?

To get started, let's examine how we can measure a small amount of evaporation from our test glass. We can use the following formula to measure the rate of evaporation in grams per second:

$$\left(\frac{Weight_{Day\,1} - Weight_{Day\,2}}{23\ hours} \times \frac{1\ hour}{60\ minutes} \times \frac{1\ minute}{60\ seconds} = rate\ of\ evaporation\ \frac{grams}{sec}\right)$$

Estimating and decreasing drying times of materials is an essential problem in engineering and manufacturing. Paint, liquid adhesives, and miscellaneous building materials must cure, harden, or dry as a part of many multi-step manufacturing processes. Carefully prepared drying time estimates help to optimize the manufacturing processes.

Your engineering task is to design a container to capture water expelled from a spray bottle and then measure that expelled amount.

3. Procedure

3.1. Before the Activity

1. Display a glass or beaker of water on a desk.
2. Use an electronic balance to measure the glass of water between two time periods. For example, during a 24-hour period between the start of the activity and the next day. Make a note of the glass or beaker and its contents one day before you begin the activity.

3.2. During the Activity

With the Students

1. Divide the class into groups of three or four students each.
2. Introduce the activity, the engineering challenge, and (as an optional extension) show a video of a manufacturing painting process.
3. Refer to the glass or beaker from the previous class. Ask students what may have happened to the water level in the glass or beaker.

- Weigh the water and give students both the previous day’s weight and today’s weight.

4. Ask students to work in groups to discuss how they can tell how much water evaporates in an hour, based on knowing the previous and current weight as well as the time difference between measuring periods.

    - Guide students through the process of dimensional analysis (see Figure 1) as they discuss in groups.

5. Write each group’s final answer as to how many milliliters of water evaporates in 1 hour.
6. Spray a single spritz of water in the air; compare this to a paint applicator that applies a powder coat or spray paint to a piece of sports equipment.

    - Ask students how much water they think they released into the air— how might they calculate the amount? If they knew how much water was expelled from the water bottle, they could also calculate the drying time.

7. Show students the various supplies and measuring device you have available for them to use.
8. Distribute copies of the Student Worksheet. Give students their mission of calculating the drying time of one spritz of water; infer they must first know the weight of a spritz of water.
9. Students then work on building a device to catch a spritz of water.
10. Students test their device and iterate their device. Remind students that exact drying times are required within a manufacturing setting; it is important for manufacturing engineers to iterate their designs so they can calculate exact drying times.
11. Students measure the weight of the water and calculate the drying time.
12. Regroup for a class discussion about their calculated drying time of a spritz of water.

4. Vocabulary/Definitions

dimensional analysis: A method of analysis in which physical quantities are expressed in terms of their fundamental dimensions that is often used when there is not enough information to set up precise equations.

evaporation: The process of turning from liquid to vapor.

5. Assessment

5.1. Pre-Activity Assessment

Brainstorming: In small groups, have students predict what will happen to a glass of water if it is left out overnight. Remind them to be specific when explaining quantifiable things and explain their reasoning.

5.2. Formative (Activity Embedded) Assessment

Class Discussion: Students report their final evaporation rate for one spritz of water including the methods they used to arrive at that number. Each group is likely to have a different number; ask students why this number may not be the same from each group.

5.3. Summative (Post-Activity) Assessment

Exit Ticket: Have students complete an exit ticket asking them to write down three things they learned from the activity, two difficulties they had to overcome, and one moment they felt successful.

6. Troubleshooting Tips

The largest obstacle to overcome is that one spritz of water is likely not detectable using an *average* electronic scale. Prepare to guide students towards alternate ways of discovering the weight of an average spritz of water. See the Additional Teacher Resources document for a walkthrough of the design process.

7. Activity Scaling

- For lower grades, provide students with fewer materials for their building challenge. Also consider scaffolding the concept that taking an average of a collection of spritzes would result in the measurement of a single spritz.
- For higher grades, have students take temperature and/or humidity into account for their drying time. Students may wish to investigate ways to control either of the aforementioned variables.

<u>Student Manual</u>

8. Summary

Reducing the drying (evaporation) time and/or time in between coats, and the amount of paint used is an important optimization problem in engineering and manufacturing. The activity will give you an opportunity to explore evaporation phenomena in classroom and visualize how evaporation time estimates data can help form an Industry 4.0 (I4.0) environment, and specifically Smart Manufacturing. You will design a container that holds exactly one spritz of water from a spray bottle. You will measure the mass of the collected liquid, or spritz, and calculate the time for the water to vaporize using a formula for an experimental rate of evaporation. After understanding the rate of evaporation, you will iterate their designs and practice dimensional analysis to further analyze the data.

9. Industry 4.0 Connection

Reducing drying times and the amount of materials used is an important optimization problem in engineering and manufacturing. Paint, liquid adhesives, and other liquid materials for machine manufacturing and building construction must cure, harden, or dry as a part of many multi-step manufacturing processes. Carefully prepared drying time estimates help to optimize the manufacturing processes. The new challenges to the economy and current world trends require the upgrade of existing manufacturing processes to the new I4.0 environment for the companies to stay competitive on the world market. Cyber-physical systems of I4.0 provide expanded opportunities for the application of drying time estimates in manufacturing. Smart Manufacturing is the new reality, where computer and automation technologies are brought to a new level of synergy. For example, drying time data could be continuously uploaded to Cloud and processed accordingly (i.e., evaluation, estimation). The production equipment at a Smart Manufacturing factory would automatically adjust painting process based on the input from the specific paint batch in the specific steps of the process in given conditions during a given timeframe. As a result, the company, owning the factory, would have an optimized, self-regulating *dynamic* process, with decreased resource (paint) use and reduced production (painting) time. Smart Manufacturing factory will allow the company to achieve the balance between the essential need for profitability and the sustainability agenda driven by the community and government.

10. Learning Objectives

After this activity, you should be able to:

- Define evaporation as applied to manufacturing;
- Design, conduct, and analyze a sample evaporation process:
  - Determine the mass of an unknown volume of liquid,
  - Use iterative design to validate test results,
  - Employ dimensional analysis to convert one unit to another;
- Define Smart Manufacturing and Industry 4.0;
- Discuss how evaporation times data can help build Smart Manufacturing environment;
- Recognize the value of teamwork and collaboration.

Student Worksheet

We have seen how drying times are important to know within manufacturing settings. Your task is to calculate how long it will take for a spritz of water to evaporate. Each group will be given water bottles, along with various equipment for data collection. Your task will be to measure and calculate the exact time, to the nearest second, for one full and complete spritz of water from the provided water bottle, under known atmospheric conditions (that is, inside the classroom). Equipment (suggested but not limited to): test tubes, petri dishes, paper towel, sponges, triple beam balance and/or electronic scale.

Complete the task using the seven engineering practices below:

1. **Asking Questions and Defining Problems.**

What is the exact dry time (to the nearest second) for one full and complete spritz of water?

2. **Developing and Using Models**

Draw or write an explanation of how the team expects to solve the problem. Be sure to note constraints and equipment.

3. Planning and Carrying Out Investigations

- How will your group collect the water?
- How much water is needed to get a good reading from the scales?
- What is the mass of one full and complete spritz of water?

4. Analyzing and Interpreting Data

Use this space for the data and measurement collected.

5. Using Mathematics and Computational Thinking

Use this space for the mathematical calculations and unit conversions.

6. **Constructing Explanations and Designing Solutions.**

Use the models and explanations developed. The data and mathematical calculations will prove the deduced solutions.

7. **Engaging in Argument from Evidence**

Discuss your model, explanation, and data with two other groups. All three data sets must compare the mass of water per spritz and the dry time of spritz.