Industry 4.0 and Holistic Safety Programs Industry Collaboration in Manufacturing Engineering

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Abstract

The Manufacturing and Mechanical Engineering Technology Department (MMET) at Michigan Technological University offers the Industry 4.0 Concepts and Key Factors of Holistic Safety courses. These courses are included in the newly established graduate certificate (CME) and the Master of Science in Manufacturing Engineering (MSME). The SME Four Pillars of Manufacturing Engineering inspired the curriculum design in both the CME and MSME. The courses are offered Online to suit graduates and industry professionals from electrical or computer engineering, materials science and engineering, manufacturing engineering, mechanical engineering, and engineering technology degree programs.

Discussed here are the industry collaborations that have influenced the courses *i*. Course assignments and student course evaluations will be used to assess the level of meeting the course learning objectives. Industrial collaborators play a significant role in the methods of course delivery and content covered.

Introduction/Background

The Industry 4.0 Concepts course is a three-credit course that is an examination of Industry 4.0 as it relates to manufacturing. Topics include smart factories, cyber physical systems, proactive maintenance, computer simulation, horizontal and vertical integration, and barriers to implementation. Four main learning objectives are used in the course design. These are to illustrate how the interconnection of machines and people connect to form the Internet of Things (IoT), demonstrate how information transparency is accomplished, propose Decentralized Decisions, and to assess the shifting role of human operators to strategic decision-maker and problem-solver roles. To assist in achieving these learning objectives, a grant award was received from the Association for Iron and Steel Technology (AIST) foundation to help with curriculum development. The award is being used to help students apply this knowledge and utilize Michigan Tech's Material Science Department pilot-scale metal/steel processing facility by updating the sensors and data collection capabilities. This analysis of process (big) data, with techniques such as machine learning is intended to help produce highly capable manufacturing and mechanical engineering technology engineers for the steel industry.

Key Factors of Holistic Safety is a unique one-credit course that is scheduled as two hours of lab-based instruction. The course is currently offered in-person but is planned to be Online in the near future. This course was developed in conjunction with Ross Controls and Donald Engineering. Ross Controls engineers and manufactures safe, energy efficient pneumatic controls, safety valves, and other fluid power components across the globe. Donald Engineering distributes top quality fluid power and motion control products, accessories, and provides engineering solutions for their customer needs. The company president from Donald Engineering and the global vp of safety business development from Ross Controls both provided guest lectures, training materials and equipment stations with safety sensors and with integrated safety logic devices to help develop the course. Topics include best safety practices with respect to; risk management, lockout/energy isolation, fluid power and electrical symbols, basic circuit design and machine design, and sequence of operation involved with automation controls and mechanical motion.

Collaborations with industry partners have helped influence courses in the newly established graduate certificate in Manufacturing Engineering and the Master of Science in Manufacturing Engineering at Michigan Technological University. This assessment reviews how course assignments and student evaluations will be used to assess the level of meeting course learning objectives.

Industry 4.0 Concepts Course

With Industry 4.0 being a popular advanced manufacturing topic, Industry 4.0 STEM education research calls for a revision of manufacturing related curriculum [1], [2]. Because the manufacturing industry is changing rapidly, this makes Industry 4.0 courses important in shaping the future of advanced manufacturing [3]. The Four Pillars of Manufacturing Knowledge, defined by the Society of Manufacturing Engineers [4], serves as an excellent tool used as a guide for the Industry 4.0 course. The four pillars are aligned with ABET Accreditation Standards for Manufacturing Engineering [5], and the SME Body of Knowledge [6].

In the Industry 4.0 Concepts course, students examine Industry 4.0 as it relates to manufacturing. Industrial collaborations help influence this course design. Four main learning objectives are used in the course design:

1) Illustrate how the interconnection of machines, devices, sensors, and people connect the Internet of Things (IoT) and Internet of People (IoP) to form the Internet of Everything (IoE).
2) Demonstrate how information transparency is accomplished through tasks from the virtual and physical world.
3) Propose decentralized decisions based on the interconnection of objects and people, along with information transparency.
4) Assess the shifting role of humans operating machines towards a strategic decisionmaker and problem-solver role.

To assist in achieving these learning objectives, a grant award was received from the Association for Iron and Steel Technology (AIST) foundation [7] to help with curriculum development. The award is being used to help students apply this knowledge and utilize Michigan Tech’s Material Science Department pilot-scale metal/steel processing facility by updating the sensors and data collection capabilities.

The current metal/steel processing facility at Michigan Tech is a fully operational and functional processing facility with steel casting, rolling, forging, stamping, and additive manufacturing capabilities. However, the facility does not meet Industry 4.0 standards. To implement Industry 4.0 technologies and practices, a Steel Curriculum Development Grant award was received from the Association for Iron & Steel Technology (AIST) [7]. A project team was formed through Advanced Metalworks Enterprise at Michigan Tech, where a team of students were tasked to select a process and update it with Industry 4.0 capable technology. The student team met with the advisors on a bi-weekly basis throughout the academic year.

The process chosen to introduce Industry 4.0 technology was the metal melt and casting line. To improve the process for improvement, temperature measurement for the melt and molds were identified as being important to automatically collect for process improvement. The current metal melt and casting line has the following temperature measurement instrumentation:

- Manual melt temperature measurement – Heraeus temperature display
- Mold thermocouple temperature measurement – connected to a stand-alone computer
- Thermal analysis (MeltLab) – connected to a stand-alone computer

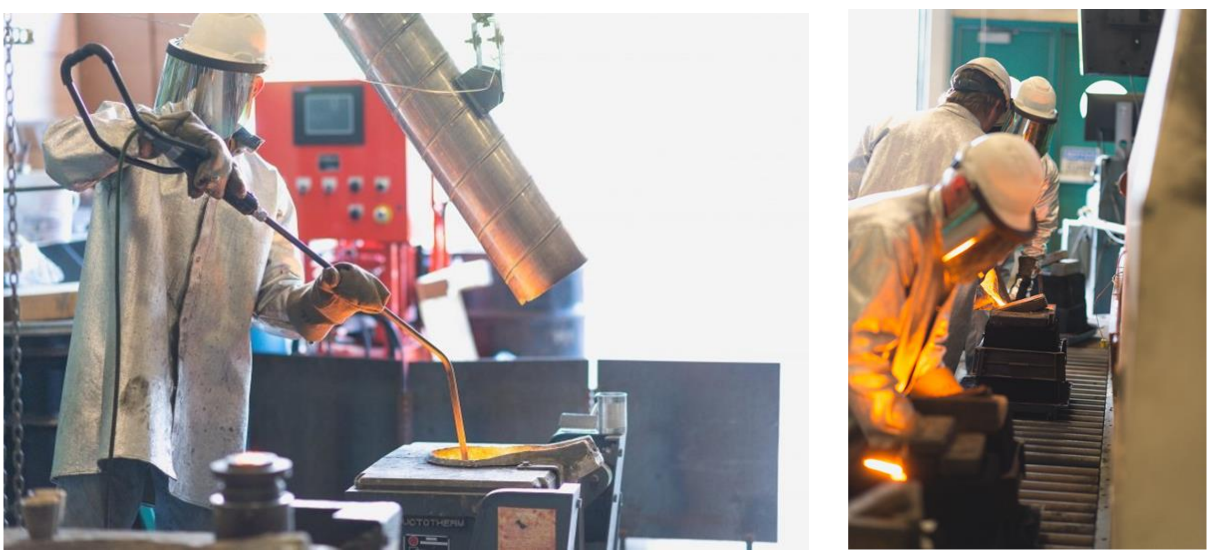

Fig. 1. Melt temperature measurement and casting line mold set up with wired thermocouples.

The goal of this effort was to automatically collect and log these data to a central database, as opposed to collecting data manually or having data stored on local non-networked computers. While trying to better align the facilities with current Industry 4.0 practices other considerations are: ease of use, maximize efficiency, better process reliability/repeatability, and improved overall safety. By making improvements with all these considerations in mind a more beneficial learning environment for tech students can be created.

To introduce Industry 4.0 technologies to the metal melt/casting line three areas, see Fig. 1, were identified to upgrade with sensors that automatically log data during the melting and casting process.

1. Melt temperature measurement with wireless connection
2. Mold temperature measurement with thermocouples and wireless recording
3. Video recording of the entire process

The first upgrade was for the melt temperature recording process. A new wireless temperature module with a wireless temperature probe, see Fig. 2, was purchased to allow the automatic recording of the melt temperature in real time. This not only produces real time measurement data but improves safety around the melt furnace by eliminating the trip hazard from the temperature probe cord. This system is installed and ready to collect data.

Fig. 2. Upgraded wireless temperature display module and wireless probe.

The second improvement was logging mold cooling data from the casting line. The students selected an Arduino microprocessor, and added wireless capability, and a thermocouple module to monitor multiple molds, see Fig. 3. The method will capture cooling data and automatically log the data onto the cloud for processing. Commercial thermocouples logging systems were initially evaluated, but due to slow logging rates the students decided to use open-source hardware to improve the real-time data collection rate. Once this capability is developed, additional commercial alternatives will be evaluated.

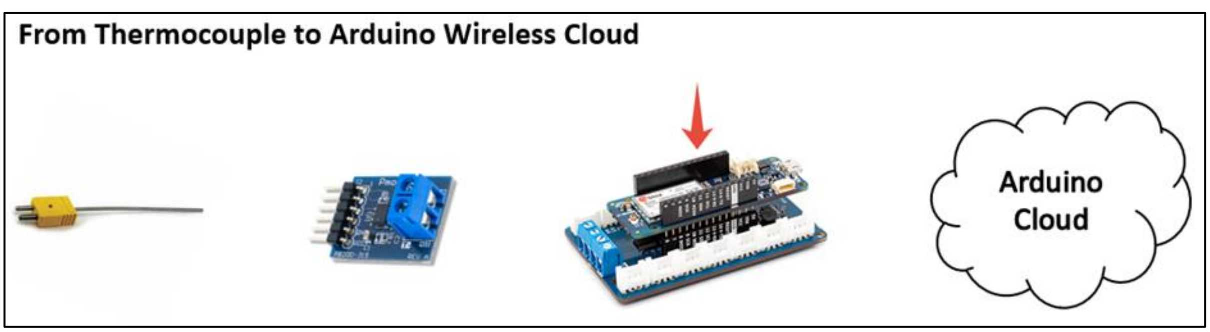

Fig. 3. Mold temperature recording process with an Arduino microprocessor with wireless capabilities.

The third data stream is a video recording of the entire melting and casting process, shown in Fig. 4, for a visual recording of the casting process. This will serve as a teaching point for future class settings. The team was able to install two cameras for the sole purpose of research only. Once the cameras are functional, recording operations will take place and be used.

Fig. 4. Closed circuit cameras installed to track the casting process.

Key Factors of Holistic Safety Course

Graduates of the MS Mechatronics degree play an important role in industry as equipment becomes outfitted with additional sensors to assist the companies by collecting data. This data is used to improve operational productivity and to protect the operators performing the essential daily duties. The intent is always good, however many times, the strategy to implement and integrate the proper safety controls is not sufficient to meet current standards. This course emphasizes the importance of performing a thorough risk assessment of the systems the students will manufacture, specify, or purchase in the future. The importance of developing and maintaining proper documentation of the systems designed is also highly stressed.

Occupational Safety and Health Administrative (OSHA) standards and requirements are looked at right at the start of the course. These standards are directly related to the machinery directive standards that many of the graduates will encounter when working with European companies. Both organizations are the laws that define the legal requirements companies are required to meet in the United States and Europe. These laws do not tell how to do anything; that is what the standards are for. These standards define the methods that are used to prove compliance. The structure of these standards is shown in Fig. 5.

Many case studies are presented that showcase the impact of when either proper safety controls were not implemented on existing equipment or when operators took matters in their own hands and bypassed critical safety equipment. In most cases, workers with significant experience are the affected employees who are either gravely or fatally injured. In these cases, not only are the injured people suffering, but also the managers and occasionally the engineers are held responsible and put on trial.

International Safety Standards Levels

Type A Basic Standards	Fundamental safety standards applicable to all machinery. • Basic concepts • Principles for design • General aspects
Type B Application Standards	Standards applicable to a wide range of machinery. Type B is divided in two categories B1 and B2. B1 – Specific safety aspects: • Safety distances • Surface temperature • Noise B2 – Safety related devices: • Two-handed controls • Interlocking devices • Pressure sensitive devices • Guards
Type C Specific Machine Standards	Standards applicable to specific machinery. • Vertical standards covering a single type of machine or group of machines • Use A or B standards to create C standards

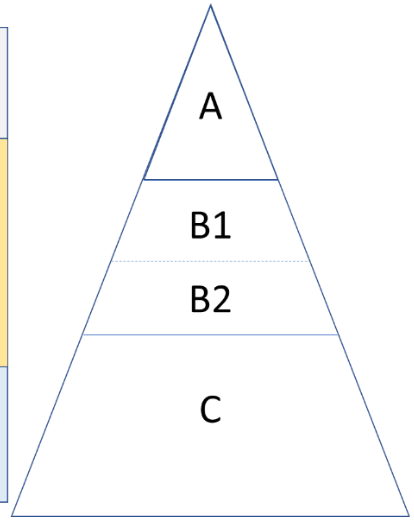

Fig. 5. International safety standards.

Risk assessment and risk reduction are also covered extensively. Both ISO and ANSI codes are reviewed and discussed (see Figure 6 for the ANSI Risk Assessment Process Flowchart).

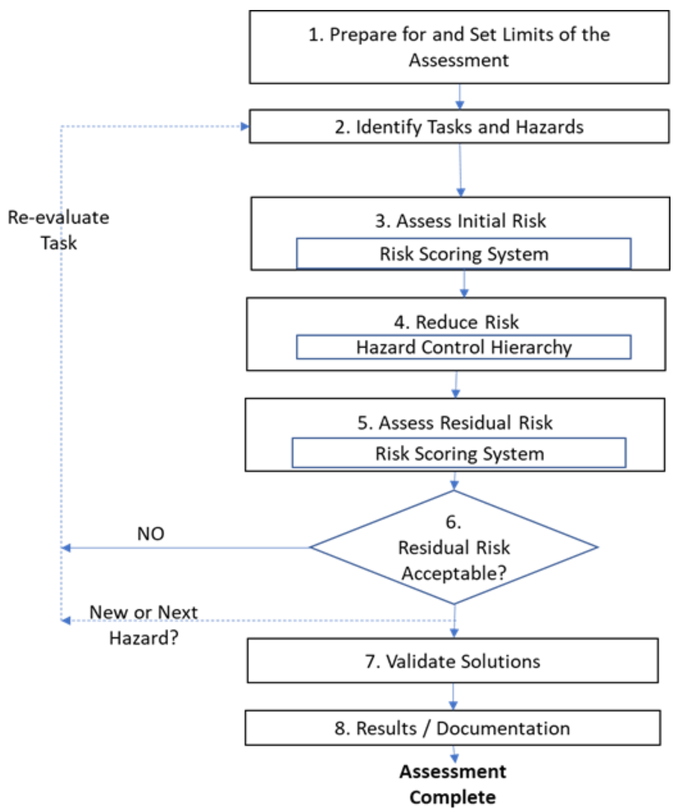

Fig. 6. ANSI B11.0 risk assessment process flowchart.

In the risk assessment portion, the following are addressed:

- Determine the limits
- Identify the hazards
- Estimate the risk
- Evaluate the risk

Whereas, in the risk reduction section, the following are performed:

- Reduction by design measures
- Reduction by guarding
- Reduction by safeguards
- Reduction by information

Finally, in this course a lot of effort is placed on informing and using many sensors related safety devices that are used in the field. The students review PLCs, pneumatic safety control valves and several safety integrated switches (shown in Figures 7-10).

Fig. 7. Safety demo with pneumatic lockout and electronic control valve.

Proper pneumatic exhausting and specifying the required electronic control valving and PLC logic are reviewed.

Fig. 8. Safety door latch and control valving.

Different strategies for protecting the operator, company and the controls engineer are observed and discussed. The requirements for a safety-controlled system are shown both in the ISO or ANSI specifications but also with hands-on application.

Fig. 9. Safety demo with light curtains and electronic control valving.

A difference in equipment controls strategies is necessary because in many cases if the safety solution is very cumbersome or complex to use, people find ways to bypass the very devices that are in place for their own safety. As a result, a number of safety solutions and safety controlling devices are presented and discussed to help the students with their future decisions.

Fig. 10. PLC with integrated safety relays.

Controlling safety logic devices are also presented and reviewed. The students are then able to analyze the PLC logic alongside the actual safety controlling equipment. It is extremely important for the students to experience firsthand how equipment is de-energized, the forces involved with powered systems and the safe distances considered when implementing proper machine guarding. These demos and labs assist the students with developing their safety solution strategies to reduce risk and safely control the equipment.

Student Feedback from Industry 4.0 and Holistic Safety Course Evaluations

To provide feedback for the Industry 4.0 course, comments from the Spring 2023 course evaluation were evaluated. The course evaluation was taken by all 13 students enrolled in the course. Comments from the student survey were evaluated to determine if any of the students commented on the Industry 4.0 project. Two comment questions asked:

- "As I, the instructor, prepare to teach this class again, what aspects of this course (teaching methods, assignments, areas of emphasis, etc.) should I preserve that effectively furthered your learning?"
- "What aspects of this course should I change to improve student learning? Specifically, what would you suggest?"

Of the two questions asked, three comments were received related to the Industry 4.0 project under the first question of preparing to teach the class again. They were "I liked the Industry 4.0 project," "Add more examples similar to the Industry 4.0 example," and "Can you show the data recorded from the foundry project?" Further discussions with students indicated they were really interested in the Industry 4.0 project in the MTU foundry, and they would like to learn more about it once the project has been completed. Once the foundry project is completed, a specific student survey will be conducted to determine how the learning objectives are being met.

Regarding the Holistic Safety course student evaluations, similar comments were made by students about the course delivery and materials covered. Although the class had 20 enrolled students, 10 filled out the evaluations and only a few comments were made by a few students. Of the fill in comments, "Labs and attendance" were highly regarded and were recommended to be preserved. And for course improvements, it was recommended that "the lab work should be more than the class lectures."

Overall, the course evaluations and student feedback are reviewed each semester to ensure a quality outcome for the students. Since these courses are newly offered, the subsequent evaluations and student feedback will be taken seriously to help improve course content. Having additional examples of Industry 4.0 type projects was a common comment. Since students come from a variety of backgrounds, their interest may or may not be in foundry applications. Having more industrial examples will aid in content delivery. In addition, having more hands-on experiences like with the Holistic Safety course proves to be a highly regarded course activity. All these suggestions will help to improve the future student outcomes.

Conclusion & Recommendations

Although the course evaluations did not contain a lot of information on the Industry 4.0 project or the Holistic Safety course, discussions with students throughout the courses did provide some valuable feedback. The students were extremely interested in seeing how this technology can be implemented in a setting such as a foundry, where very little data collection is being used, and create a potential improvement in the process. It also showed an actual application of how Industry 4.0 concepts can be implemented in an industrial setting. As for holistic safety, the students are more aware of the work they will be doing, and their responsibilities and the potential challenges they will see when they start to work in industry.

To help integrate improved topics in the Industry 4.0 and Holistic Safety courses, industry collaborations will continue to be used in the course improvement. These collaborations have indicated the students are interested and want to learn more. In addition to the current collaborations that have been used, additional industrial collaborations and reviewers will be approached for their valuable insights, feedback and future recommendations.

References

[1] Alasti, H. (2021, July). Turning a Legacy Robot to Collaborate to Fit in Industry 4.0 Demands Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. https://peer.asee.org/37941

[2] Das, S., & Kleinke, D. K., & Pistrui, D. (2021, July). 2020 BEST PIC V PAPER WINNER - Reimagining Engineering Education: Does Industry 4.0 Need Education 4.0? Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. 10.18260/1-2--36545

[3] Huderson, A., & Peiffer, E., & Shamsi, S., & Plaza, F., & Collins, E. (2022, August), Future of Mechanical Engineering, Manufacturing Engineering, and Machinist Roles For Industry4.0. Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/41625

[4] SME (2011), "Four Pillars of Manufacturing Knowledge." Accessed from www.sme.org/fourpillars

[5] ABET, Inc. (2022). "Accreditation Standards and Program Criteria for Manufacturing Engineering and Similarly Named Programs." Washington, D.C.: ABET, Inc. Accessed from http://abet.org/engineering-criteria-2022-2023/

[6] SME (2020). "Certified Manufacturing Engineering Technologist and Certified Manufacturing Engineer - Body of Knowledge 2020." Dearborn, MI: Society of Manufacturing Engineers. Accessed from https://www.sme.org/globalassets/sme.org/training/certifications/technical-certification/technical-certification-body-of-knowledge.pdf

[7] Association for Iron & Steel Technology (AIST) https://www.aist.org

[8] Ross Controls (2021), Fluid Power Machinery Safety Guidebook (pp. 6-13)

Biographies

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