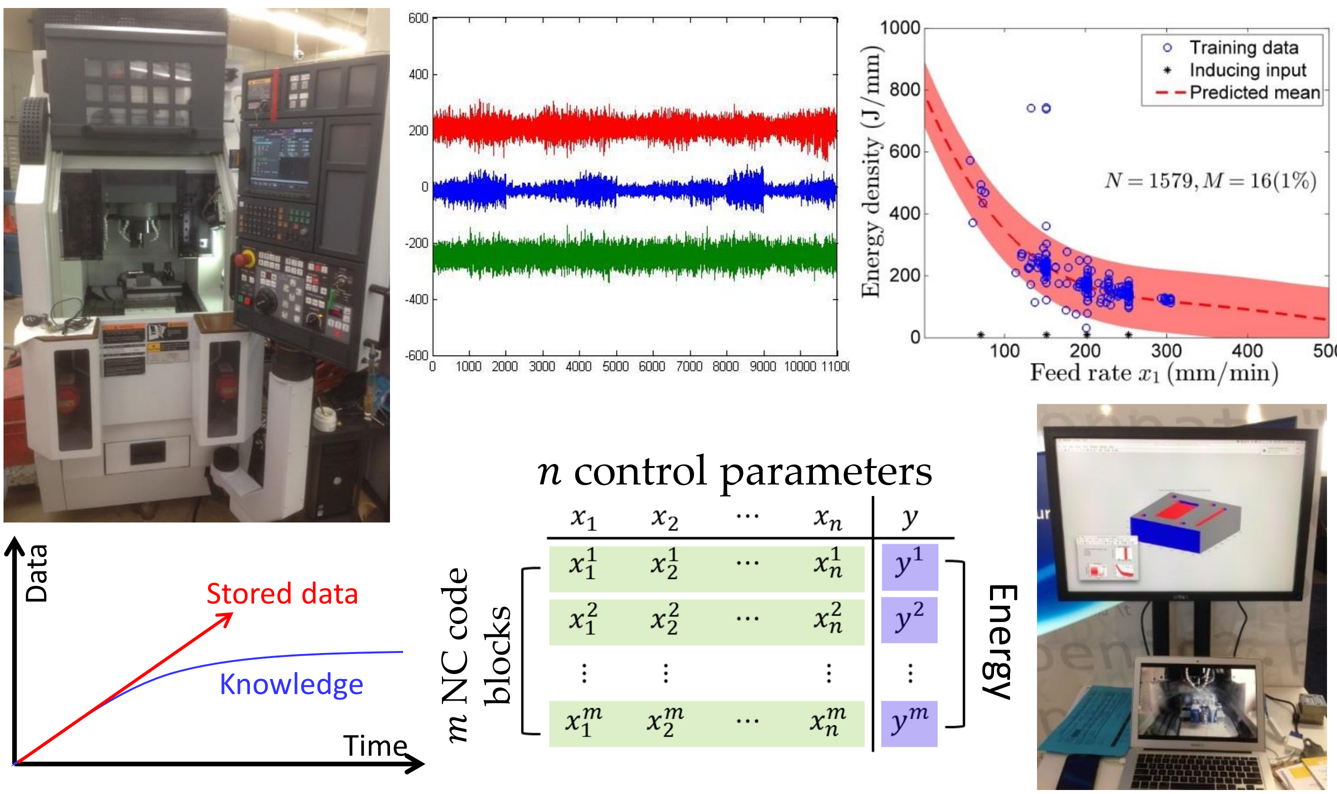
MTConnect Student Challenge: Idea Creation

A Pedagogical MTConnect Module to Improve Scaffolded Active Learning in Manufacturing Engineering Education



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Abstract

Recent interest in improving pedagogical approaches in science, technology, engineering, and mathematics (STEM) fields has stimulated research at many universities. It is found that there is an essential need to identify and overcome the STEM educational challenges. Thus, this proposal aims to support student learning in manufacturing engineering through continuous machine monitoring and real-time process evaluations. A pedagogical framework is presented as an idea that can assist engineering educators in developing MTConnect learning modules in both academia and industry communities. Manufacturing education requires engagement of students and engineers in psychomotive learning to facilitate content comprehension, connect learning goals, and clarify the subjects. Advances in sensor technologies and development of standards in smart manufacturing have made it possible to retrieve real-time data efficiently from machine tools. The proposed framework is applied to develop a participatory pedagogy for manufacturing courses through the use of computer numerical control of manufacturing operations and MTConnect as a machine interoperability standard for real-time monitoring, visualization, and data analysis of machine energy use. The framework has been applied for graduate manufacturing engineering course at University of California (UC), Berkeley. It is found that the framework can effectively support MTConnect learning module development in manufacturing engineering education.

1. Proposed idea

The overarching goal of this idea is to improve students' and engineers' understanding of smart and sustainable manufacturing at the macro and micro level and to bridge the gap between knowledge discovery and technology implementation in manufacturing. The specific goal is to develop a pedagogical framework to assist engineering educators in developing MTConnect learning modules, and subsequently, support learners in manufacturing engineering communities. The presented idea here supports the new active learning resources to improve participatory pedagogy and educate undergraduate/graduate engineering students in various manufacturing areas (e.g., sustainable production, manufacturing process performance, and energy analysis).

Recent studies indicate that active learning leads to improvements in learning efficiency and effectiveness[1]. Freeman et al. (2014) reported that active learning offers greater benefit than traditional lecturing across the STEM disciplines, exhibiting an average examination score improvement of about 6%. Applying computers and machines in evidence-based teaching to build conceptual learning in engineering and manufacturing courses can maximize student achievement and improve competency and skills[2].

Since innovation and technology in manufacturing play a key role, manufacturing education has the potential to use active learning resources and educational technologies to create a more effective pedagogical method[3]. Subsequently, the proposed idea explores whether the active learning resources and tools (e.g., MTConnect standard) are conducive to meeting manufacturing engineering course learning outcomes (e.g., the effect of process parameters on machine energy use), as well as comparing and critiquing existing educational approaches, especially in machining processes and real-time data analytics.

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[1]Scott Freeman et al., “Active Learning Increases Student Performance in Science, Engineering, and Mathematics,” *Proceedings of the National Academy of Sciences* 111, no. 23 (2014): 8410–15.
[2]Bill Ferster, *Teaching Machines: Learning from the Intersection of Education and Technology* (JHU Press, 2014).
[3]Susan Singer and Karl A. Smith, “Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering,” *Journal of Engineering Education* 102, no. 4 (2013): 468–71.

The idea presented herein encompasses a framework (Figure 1) to assist the educators in creating the MTConnect learning module in manufacturing engineering courses. The learning module framework aims to foster student and engineer learning and immersion into engineering courses through experimentation (psychomotor domain), and analyzing and evaluating (cognitive domain). Psychomotor development has traditionally received less attention due to increased resource needs (e.g., lab equipment). The focus here is on active learning resources to support the psychomotor domain.

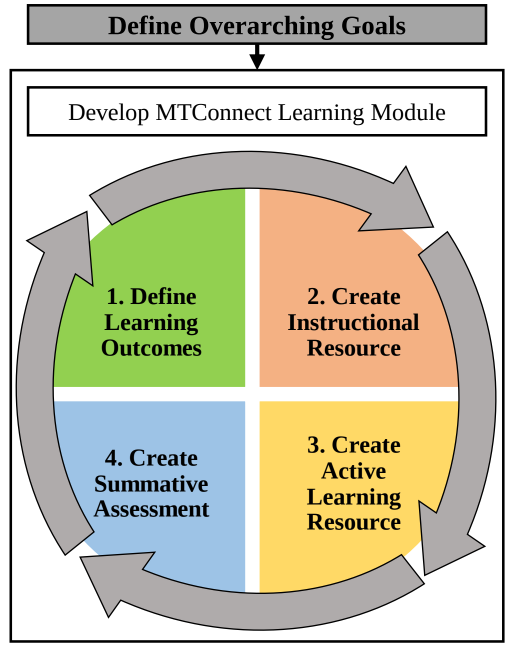

Figure 1. MTConnect learning module framework

Active Learning Resources emphasize participatory pedagogy and assist learners in the analysis and evaluation of manufacturing processes, while scaffolding learning from a higher level to lower level of educator support. Figure 2 indicates the main manufacturing functions, which are connected through active experimentation and real-time data analytics as a multi-disciplinary approach to manufacturing engineering education. Hands-on activities in the presented learning module framework are supported by MTConnect to facilitate education.

Training of future engineers in this manner will enable the continued performance improvement of manufacturing industry beyond addressing technical process challenges, but also in addressing broader sustainable manufacturing challenges through life cycle assessment, energy monitoring and analysis, process optimization, social assessment, and other approaches.

Existing curricula and learning resources are deficient in training students and engineers to overcome the emerging manufacturing challenges through the lens of sustainability[4]. Allen et al. (2009) addressed several gaps in engineering courses, such as, the lack of engineering educators' expertise and the lack of technical materials to support educators. This situation demands the development of campus-based instructional capabilities to support manufacturing engineering education. Specifically, equipment and scaffolded (instructor-supported) learning materials are needed to support hands-on experimentation, analysis, and real-time monitoring and control of manufacturing processes. Thus, the benefit and the impact of the proposed idea is mainly on manufacturing engineering curricula and learning resources.

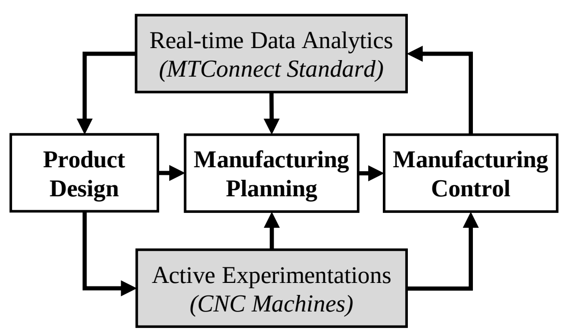

Figure 2. Manufacturing functions and integrated active learning approaches (shaded boxes)

Real-time data analytics as an active learning resource of a manufacturing process for monitoring, visualization, and prediction of various parameters can greatly improve manufacturing education across the different universities and industries. Advances in sensor technologies and development

[4]David Allen et al., "Benchmarking Sustainable Engineering Education: Final Report," U.S. EPA (Grant No. X3-83235101-0 (University of Texas at Austin, Carnegie Mellon University, Arizona State University, 2009).

of data standards have made it possible to retrieve real-time data efficiently from machine tools in smart and sustainable manufacturing[5], thereby enabling access to manufacturing information from the classroom via the internet.

In addition to the continued development of novel manufacturing processes, recent interest in smart manufacturing and automated process planning supported by new technologies and standards (e.g., MTConnect standard) has stimulated research and educational developments[6]. Recent advances in technologies such as manufacturing tools can address some of the challenges in the engineering field. Manufacturing organizations need new solutions to improve their efficiency, and subsequently, reduce overall cost through new emerging technologies. These technologies can be adapted to the learning environment to support mechanistic understanding of manufacturing processes and process performance, in addition to familiarizing students with the application of sensor technologies, monitoring, and analysis approaches.

Hands-on education on manual machine tools (e.g., mills and lathes) and CNC machines is an integral part of manufacturing education. The lack of visibility and control into these automated processes is one of the key challenges in using CNC milling and turning machines. Burrs, chips, and flood coolant often obstruct the view of any machining process and it is extremely difficult to know the operation in progress until the part is completely machined. The MTConnect standard has emerged to efficiently extract real-time data and develop machine learning models for equipment and process characterization, and energy prediction and monitoring[7]. The MTConnect standard is an interoperability standard that facilitates archiving, accessing, and retrieving operational data from manufacturing equipment[8].

Machine tool monitoring is a very important feature in precision manufacturing. Using block-by-block operational data, a machine learning model can be trained and be developed for energy prediction[9]. Previous research has shown over 95% accuracy in these energy predictions, which points to the fact that the MTConnect shop data can be used as a reliable source for machine tool monitoring and anomaly detection. Real-time online algorithms for energy prediction have been developed in previous and on-going research[10]. Simultaneous visualization of actual and predicted energy consumption can give insights into the manufacturing process, such as unexpected energy spikes and increasing trends in the energy consumption due to tool wear.

The proposed idea integrates machine- and data-driven manufacturing, which involves the use of CNC machines and MTConnect to improve the quality of manufacturing education, utilizing real-time data visualization, and machine learning technologies. Through the integrated approach, manufacturing engineering students will gain insight into defining system boundaries to accomplish effective analyses of parameters for creating discrete manufactured products. Additionally, students will better understand the purpose for smart manufacturing development and the role of conventional subtractive processes by considering the cumulative sustainability impacts through real-time monitoring and analyses. This idea has been applied for Precision

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[5]Roberto Teti et al., "Advanced Monitoring of Machining Operations," *CIRP Annals-Manufacturing Technology* 59, no. 2 (2010): 717–39.
[6]Jim Davis et al., "Smart Manufacturing," *Annual Review of Chemical and Biomolecular Engineering*, no. 0 (2015), http://www.annualreviews.org/doi/abs/10.1146/annurev-chembioeng-061114-123255.
[7]Athulan Vijayaraghavan and David Dornfeld, "Automated Energy Monitoring of Machine Tools," *CIRP Annals-Manufacturing Technology* 59, no. 1 (2010): 21–24.
[8]MTConnect Institute, "MTConnect v. 1.3.0," 2015, http://www.mtconnect.org/downloads/standard.aspx.
[9]Jinkyoo Park et al., "A Generalized Data-Driven Energy Prediction Model with Uncertainty for a Milling Machine Tool Using Gaussian Process," 2015, http://minoe.stanford.edu/publications/jinkyoo_park/MSEC2015.docx.
[10]Jinkyoo Park et al., "Real-Time Energy Prediction for a Milling Machine Tool Using Sparse Gaussian Process Regression," in *IEEE International Conference*, 2015.

Manufacturing course (ME 220) at UC Berkeley to assess the effectiveness of the proposed module framework, utilizing the MTConnect learning module. This proposal is part of larger educational effort investigating a pedagogical module framework to improve scaffolded active learning in manufacturing engineering education. The results have been submitted to the 44th North American Manufacturing Research Conference (NAMRC)[11] at Virginia Tech in 2016 to present the proposed learning module framework. The authors wish to submit this study in Journal of Manufacturing Systems after conducting the summative assessment and achieving the student's feedback about this learning module.

2. Technical Requirements

In order to implement the proposed idea in an educational environment, the most important requirements are a machine tool with an MTConnect adaptor and at least one external sensor such as a power meter. Figure 3 demonstrates the requirements of continuous machine monitoring and control process for real time data acquisition and adaptive machine learning, using MTConnect agent. Other technical requirements include the ability to extract the data from the machine tool controller and the power meter simultaneously using the MTConnect protocol, ability to process the data, ability to simulate a cutting process using finite volumes to create a high-dimensional dataset and the ability to implement high-order machine learning or statistical learning algorithms.

Real-time operational data can be extracted from the target machine tool through the development of MTConnect standard. This approach has been demonstrated on a Mori Seiki milling machine tool[12] and the different types of data typically extracted are depicted in Figure 4. The instantaneous positions can be extracted from the block of code being processed in real-time. This information can be condensed and a block-by-block simulation can be demonstrated in real-time as the processing is unfolding in the machine tool[13].

Block-wise data condensation and analysis techniques developed at UC Berkeley provide the stepping stones to this idea[13]. These milestones have already been reached and this idea builds on the fact that large statistically significant datasets can be created through a block-wise data analytics technique from the machine tool controller and external sensor. Causal relationships between the NC code blocks and the resulting sensor data have already been established and used for energy prediction at UC Berkeley.

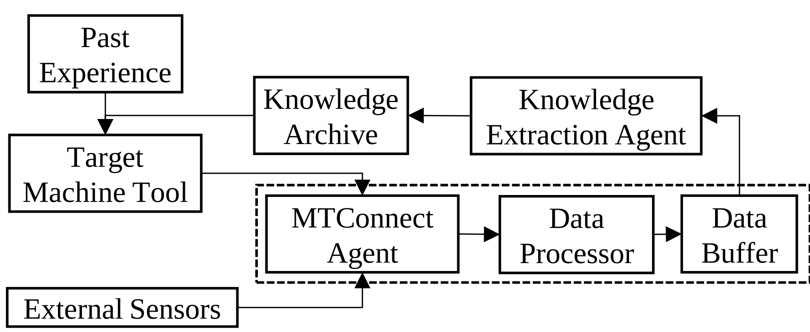

Figure 3. Continuous machine monitoring and control, using MTConnect agent

[11] Amin Mirkouei et al., "A Pedagogical Module Framework to Improve Scaffolded Active Learning in Manufacturing Engineering Education," in *Proceedings of the 44rd North American Manufacturing Research Conference*, 2015.
[12] Park et al., "Real-Time Energy Prediction for a Milling Machine Tool Using Sparse Gaussian Process Regression."
[13] Raunak Bhinge et al., "An Intelligent Machine Monitoring System for Energy Prediction Using a Gaussian Process Regression," in *Big Data (Big Data), 2014 IEEE International Conference on* (IEEE, 2014).

3. Benefits and Impact

MTConnect data

Direct data	Derived data	Simulated data
NC code block	Duration	Depth of cut
Timestamp	Energy	Cutting strategy
Feed rate	Average feed rate	Material cut vol.
Spindle speed	Avg. spindle speed	Cut classification
X, Y, Z, S loads	Length of cut in x	Material cut in x
Tool position	Length of cut in y	Material cut in y
Power	Length of cut in z	Material cut in z

Figure 4. Extracted data from a power meter and machine tool via MTConnect

The outputs (e.g., results, simulation, and visualization) can give learners a representation of the toolpaths, the on-going machining process, instantaneous geometry and type of operation, which is enriching information due to the lack of visibility and control inside the machine tool (Cover Page Figure). Insights such as greater energy consumption during conventional milling as compared to climb milling can be obtained from such contextualized data and visualization, leading to deeper understanding of the manufacturing process at a granular level.

In order to keep abreast of the rapidly changing and evolving manufacturing environment, a new section on data-driven manufacturing has been introduced into the Precision Manufacturing course curriculum. Data-driven manufacturing improves process efficiency, machine tool efficiency, throughput, uptime, and productivity at various levels in the manufacturing enterprise. With new technologies, research, and initiatives such as the fourth Industrial revolution[14] and the Industrial Internet[15], data-driven manufacturing is being viewed as the next major change in the manufacturing industry. The lecture on data-driven manufacturing is designed to bring learners up-to-date with the latest advances in the field with real-time demonstration of MTConnect and its advantages in the future of smart manufacturing.

The main return on investment (ROI) of this idea is to provide a conducive learning environment in the context of smart and sustainable manufacturing, through pedagogical support for continuous machine monitoring and real-time process evaluation. Utilizing MTConnect standard offers several benefits to industry and academia communities, such as, enables students and engineers to innovate and create new solutions for the current and future challenges in the modern world. Thus, the ROI of developing the proposed scaffolded learning module varies with the purpose of using MTConnect standard in either academia or industry community.

The primary cost of this learning module in academia, providing learning outcomes, instructional resources, active learning resources, and summative assessment mechanism, is predicted as $2000. Instructional resources provide materials for the instructor and students, including five-page general background information (literature review), which are created to support instructor learning; and 50 minutes lecture slide-set is developed to assist the instructor in delivering the fundamental concepts to the students. Active learning resources provide preparatory assignments, encompasses 30 minutes in-class examples (more instructor involvement) and homework problems (independent learning or less instructor involvement), as well as two hours hands-on experiments (laboratory activities). These resources assist students in the analysis and evaluation of manufacturing processes, while scaffolding learning from a higher level to lower level of instructor support. Summative assessment mechanism provides feedback from participants to validate the level of success and guide improvement of module materials.

[14]Jay Lee, Hung-An Kao, and Shanhu Yang, "Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment," *Procedia CIRP* 16 (2014): 3–8.
[15]Peter C. Evans and Marco Annunziata, "Industrial Internet: Pushing the Boundaries of Minds and Machines," *General Electric*, 2012, 21.