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Integrating Hands-on Continuous Process Improvement Practices with Traditional Manufacturing Processes Lab*

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Hands-on continuous process improvement and ability to train others are highly desired industry job skills for industrial and systems engineering (ISyE) graduates. It is important for higher education institutions to continuously strive for innovative curriculum and prepare their students adequately for industry. Traditional ISyE curricula typically involve fewer equipment and instrumentations compared to other engineering disciplines. As a result, ISyE students are often trained by using software, simulations and conceptual projects. To bridge the hands-on skill gap in our graduates, a new integrated manufacturing processes lab instructional pedagogy was introduced to ISyE juniors. In the new curriculum model, students were provided with the opportunity to apply continuous process improvement concept to traditional manufacturing processes while learning basic manufacturing operations and machine tools. Students either implemented their own continuous process improvement ideas on self-designed products, or trained other peers to execute their improvement proposals. A survey was conducted at the end of the lab course to assess students' experiences with the new lab curriculum and their perception of industry job skills. Results show that students highly valued the new learning experiences in the manufacturing processes lab course and wished to have more similar opportunities in their ISyE courses. Data also reveals that student perception of hands-on continuous process improvement skill and ability to train others were consistent with industry expectations with respect to the level of importance. However, students perceived the ability to train others to be more highly desired by their potential employers compared to the hands-on continuous process improvement skill, whereas industry shared the opposite expectation. The outcome of this study encourages the implementation of an integrated curriculum and instructional pedagogy model in which hands-on training of cross-cutting concepts is incorporated into traditional courses. Several areas of course improvement was also identified at the end of the study to further increase the effectiveness in preparing ISyE graduates for careers in industry.

Keywords: hands-on learning; industry skill gap; continuous process improvement; industrial and systems engineering; manufacturing processes; undergraduate lab curriculum

1. Introduction

Industrial and systems engineering is defined by the Institute of Industrial & Systems Engineers (IISE) to associate with "the design, improvement and installation of integrated systems of people, materials, information, equipment and energy" [1]. Continuous improvement is one of the featured skills and practices in the industrial and systems engineering profession across industries [2]. A Google search using keywords "industrial engineering" and "continuous improvement" yields hundreds of job results [3]. Typical job titles with a continuous improvement focus are: operational excellence engineer, continuous improvement engineer, process improvement engineer, manufacturing engineer, industrial engineer [3]. Job functions and responsibilities involve the designing or re-designing of tools/equipment to improve process, process standardization, analysis of process parameters, process troubleshooting, development of improvement strategies, identification of waste reduction opportunities, implementation and sustainment of improvement strategies [3]. In addition to the technical skills, companies also expect their engineers to be able to train others [3].

The World Economic Forum forecast the top skill demand by industries in 2022 are analytical and problem solving skills [4]. This was also emphasized by the National Academy of Engineers (NAE) as part of their "The Engineer of 2020" report [5]. According to the NAE, it is the responsibility of higher education institutions to develop, train and prepare graduates with the needed skills for the workforce so they can tackle the challenging problems currently faced by the world's population [6]. Economic development may also be significantly and negatively impacted if education and workforce training does not address industry needs [7].

According to Fraser's benchmarking study of industrial engineering and closely related programs in 2015, at least half of the 94 ABET-accredited programs required the following core industrial engineering courses: operations research, probability/statistics, engineering economics, work methods/human factors/ergonomics, simulation,

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quality, senior design project, production planning and control, manufacturing processes, and facilities/layout/material handling [8]. The average number of required credits for the degree was found to be 128.9 in 2015, compared to 129.5 required credits in 2005 [8]. Due to the high credit requirements of the program, there is very limited time, or no time, for the training of cross-cutting concept applications in the curriculum, except for senior design project. Laboratory exercises are often an important aspect in industrial and systems engineering (ISyE) curriculum [6, 9–12]. However, students often receive lab experiences through software-driven or conceptual lab exercises, mostly due to the complexity and high costs of industrial-scaled operations and processes. According to Hernández-de-Menéndez *et al.*, student learning could be sacrificed due to the disconnection between simulated and real experiments [13]. Additionally, students rely on data collected from virtually simulated labs based on simplified models which do not truly match the real-world situations [13]. Manufacturing processes labs are one of the exceptions as the training of manufacturing processes concepts is less effective when done virtually. As a result, manufacturing-related equipment is typically used for student training in an industrial engineering program in which a manufacturing processes course with a lab component is required [10].

There is a high demand for manufacturing workforce in the United States due to the baby boomer generation retirement and lack of qualified workers/engineers with the needed skills [12]. Manufacturing sector accounted for 11% of the overall gross domestic product (GDP) at the end of the first quarter of 2021, ranking fourth after the finance/insurance/real estate/rental/leasing, the professional and business services, and the government sectors [14]. Therefore, the inclusion of manufacturing processes course in a traditional ISyE undergraduate program still remains to be valuable to students and vital to the economy.

Hands-on active learning has proven to be effective in preparing students for employment in industry [15] and "stimulate motivation for learning" [16]. The "learning by doing" approach has been incorporated into the industrial and systems engineering curriculum by many programs [6, 9–12, 16–18]. For example, Lynch et al. reported successful internship and co-operative work experience programs at Texas A&M and the University of Cincinnati designed to expose students to industrial settings [12]. Marquette University utilized an active learning approach with an in-class assembly line simulation activity to teach design for manufacturing concepts [17]. The Missouri University of Science and Technology adapted a virtual simulation platform to teach students lean manufacturing methods [6]. Other industrial and related engineering programs, including those at Penn State University (United States of America), TU Dortmund University (Germany), Universidad del Norte (Colombia), Loughborough University (United Kingdom), and Rochester Institute of Technology (United States of America), implemented instructional models with projects and laboratory exercises to promote learning through scaled-down processes and systems that resemble industrial cases [9–11, 16, 18]. Most of the in-house laboratory-based experiences are developed and designed around manufacturing settings that encompass processes, operations and assembly. However, the equipment-based lab exercises mostly focus on the operations and processes rather than continuous process improvement due to the time and scope constraints within the curriculum.

2. Purpose

The purpose of this study is to assess the feasibility and effectiveness of integrating of continuous process improvement training into a traditional manufacturing processes lab curriculum. This pedagogical approach is designed to provide students with the hands-on active learning and to bridge the skill gap in industrial and systems engineering graduates to meet industry expectations. The recently tested integrated curriculum approach features continuous improvement opportunities for students while learning the basic, safe operations of machine tools and manufacturing processes. Students strive to reduce waste, increase operational efficiency and improve product quality through redesigning a product and/or process. They also have the opportunity to train other peers to test and implement potential continuous process improvement proposals. This study attempts to address three research questions:

(i) How feasible is it to integrate the teaching of manufacturing operations and hands-on continuous process improvement practices in an undergraduate industrial and systems engineering curriculum?
(ii) Is student learning experience compromised when continuous process improvement practices are embedded in a traditional manufacturing processes lab curriculum?
(iii) How do industry expectations of industrial and systems engineering graduates with respect to career readiness compare to student perception of the job skills needed for their profession?

3. Methodology

3.1 Institutional settings and ISyE program curriculum

This project took place at the University of San Diego (USD) in the ABET-accredited industrial and systems engineering (ISyE) program. USD is a contemporary liberal arts, private Catholic institution. The ISyE program offers a dual Bachelor of Science/Bachelor of Arts degree with a 4½-year standard curriculum and 147 credits requirement for graduation. The ISyE department does not currently offer any graduate degree programs or courses. ISyE student cohort size at the time of the study was 40, which is approximately the same as the average ISyE cohort size over the last three years. On average, 43% of 2016–2020 ISyE graduates were female and 33% were international students. Students are not required to declare their majors until the end of the sophomore year. They are also not required to take ISyE major-specific courses until the beginning of their junior year. Table 1 shows a standard, recommended class plan for ISyE majors at USD, focusing on junior and senior years only [19].

ISyE students at USD are first introduced to the concepts of lean and continuous improvement during the first semester of junior year, primarily through the Work Analysis and Design class (ISYE 310). As students advance to the second semester of their junior year, they learn about Six Sigma Process Improvement Methods (ISYE 335) and apply some of the continuous improvement principles in the Introduction to Systems Engineering class (ISYE 320). ISYE 335 consists of both lecture and lab components. Students apply probability and statistical concepts, previously learned in a sophomore class, and practice DMAIC (define, measure, analyze, improve, control) methodology in ISYE 335 lab exercises and project. A Lego kit is used for Six Sigma concept demonstration. After ISYE 335, students typically do not have the opportunity to practice and apply continuous improvement concepts again until senior design project, which takes place during the second semester of senior year.

3.2 Old manufacturing processes lab curriculum model

ISyE majors are required to take the Manufacturing Processes class (ISYE 350/L), both lecture and lab, during the second semester of their junior year. In the lecture portion of the course, students learn about different manufacturing processes and operations, associated equipment, materials and process design. Working in teams and individually in the lab, students apply theoretical concepts behind selected processes to design certain products, using computer-aided-design and computer-aided-manufacturing (CAD/CAM) software as needed, while taking into account material and operational constraints. Students then learn the safety and operation of machine tools needed to manufacture their products. Table 2 shows a typical schedule for ISYE 350L lab class. Traditionally, lab instruction focuses on the use of new software and safe operation of various machine tools involved in the design and production of certain products. This instructional model is found to be common across colleges and universities in the United States (e.g., Cal Poly Pomona [20], Miami University [21], Montana State University [22], University of Florida [23], West Virginia University [24]), and other countries around the world (e.g., Chalmers University of Technology in Sweden [25] and Malla Reddy College of Engineering and Technology in India [26]). Students do not have the opportunity to make

Table 1. Standard junior and senior class plan for ISyE majors at USD

Junior Year (3rd Year)			
Fall		**Spring**	
ISYE 220: Engineering Economics	3	ISYE 320: Intro to Systems Engineering	3
ISYE 310: Work Analysis & Design w/ Lab	4	ISYE 335: 6σ-Process Improvement Methods w/ Lab	4
ISYE 340: Operations Research I	3	ISYE 350/L: Manufacturing Processes w/ Lab	4
ISYE 305: Professional Practice	3	ISYE 440: Operations Research II	3
MENG/ENGR 311: Materials Science	3	ISYE Program Elective I	3
Total Hours	**16**	**Total Hours**	**17**
Senior I Year (4th Year)			
Fall		**Spring**	
ISYE 420: Simulation w/ Lab	4	ISYE 492: Senior Design Project	3
ISYE 430: Design of Experiments	3	ISYE 460: Operations & Supply Chain Management	3
ISYE 470: Facilities Planning	3	ISYE Program Elective III	3
PHIL 332/338/342/345: Ethics	3	Core Curriculum	3
ISYE Program Elective II	3	Core Curriculum	3
Total Hours	**16**	**Total Hours**	**15**

Table 2. Traditional schedule for ISYE 350L – Manufacturing Processes Lab course (14 weeks)

Week	Lab
1	Lab introduction and safety overview
2	CNC programming, part I
3	CNC programming, part II
4	CNC milling operation
5	CNC turning operation
6	Computer-aided manufacturing
7	Product (pen) design using Mastercam
8	Toolpath setup and CNC code generation with Mastercam
9	Product (pen) manufacturing processes
10	Product (pen) assembly and finishing operations
11	Plastic molding
12	Welding
13	Design for Manufacturing/Design for Assembly
14	Lab make-up day

Table 3. New schedule for ISYE 350L – Manufacturing Processes Lab course (14 weeks)

Week	Lab
1	Lab introduction and safety overview
2	CNC programming, part I
3	CNC programming, part II
4	**CNC milling: basic machine operation and process**
5	**CNC milling: continuous improvements**
6	Product (pen) design using Mastercam
7	Toolpath setup and CNC code generation with Mastercam
8	Product (pen) manufacturing processes
9	Product (pen) assembly and finishing operations
10	**Plastic molding: basic operation and processes**
11	**Plastic molding: continuous improvements**
12	Welding
13	Design for Manufacturing/Design for Assembly
14	Lab make-up day

changes to their product designs and/or manufacturing processes to improve product quality and increase operational efficiency.

3.3 New Manufacturing Processes Lab Curriculum Model

A comprehensive review of currently available literature yielded no curriculum examples of combined hands-on training of manufacturing processes and continuous process improvement practices in an undergraduate laboratory curriculum. However, there have been reports showcasing successful integration of manufacturing with other engineering and science related topics in the past. For example, the teaching of lean manufacturing principles was commonly integrated with the design and setup of assembly production lines of Lego cars at Utah State University [27], of clocks at Oregon State University [28], and of water batteries at Marquette University [17]. Ziemian and Sharma shared the "learning factory" model in which materials, design, and research concepts were integrated into the traditional instruction of manufacturing processes at Bucknell University [29]. Sengupta *et al.* modernized engineering curriculum through the introduction of sustainability concepts into traditional manufacturing processes [30]. The lack of educational model in which core industrial engineering skills, such as continuous process improvements, are taught as an integrative component of traditional manufacturing curriculum highlights the significance and innovation of this work.

Recognizing the missed opportunity for ISyE students to practice hands-on continuous improvements on industrial processes, a new, integrated manufacturing processes lab curriculum and instructional pedagogy model was proposed and implemented with ISyE majors during the second semester of their junior year. See Table 3 for the revised manufacturing processes lab schedule with changes highlighted (Weeks 4, 5, 10, 11). There was no content or concept removal in the new lab curriculum compared to the old curriculum. However, some of the manufacturing process experiences were combined and integrated in the new instructional pedagogy. Specifically, in the new model, students learn CNC turning operation in the pen manufacturing processes lab (Week 8 in Table 3) instead of separately in Week 5 and again in Week 8 as included in the old curriculum (see Table 2). Additionally, in the new curriculum, students learn the computer-aided manufacturing concept directly through the design of a ballpoint twist pen, setting up machining toolpaths and generation of CNC code using Mastercam software.

In this study, continuous improvement practices are embedded in the CNC milling lab and plastic molding lab in the new curriculum model. During the first CNC milling lab session (Week 4 in Table 3), students learn basic safety and operation of a 3-axis CNC mill and manufacture an oval nameplate with customized surface design from a PVC stock. As part of the lab, students record process cycle time, including machine setup time, actual machining time and cleanup time. Note that students create their personal design on the nameplate through manual G&M code writing during the preceding CNC programming labs (Weeks 2 and 3). Students are then asked to evaluate product outcomes against specifications and identify areas of improvement to increase product quality and operational efficiency (e.g., reducing cycle time) while maintaining safety standards. Opportunities for improvement could be drawn from the product design and manufacturing stages. For examples, students could choose to alter: toolpath selection for the machining operation (through CNC programming), procedure to set up the work coordinates, load/unload stock protocols on the mill, tool changing method and cleanup procedure. In the second session of the CNC milling lab (Week 5 in Table 3), students are given the opportunity to implement the continuous process improvement strategies that they selected after the first CNC milling lab session. Students then re-evaluate their new product outcomes against specifications and compare the individual and overall cycle times between the first and second runs. Individual lab reports with learning reflection on hands-on continuous process improvement application and experiences are expected from each student as part of the lab deliverables.

Another hands-on continuous process improvement training is also employed in the new manufacturing processes lab model under a peer training format. There are typically four groups of 3–4 students in a manufacturing process lab section. The first group of students learns the basic safety and operations of plastic injection and plastic extrusion blow molding processes directly from the lab instructor (Week 10 in Table 3). In the following week (Week 11), the same group creates a training plan and in turn trains the second group on plastic molding machine operation while sharing lessons learned from their initial lab experience. The transfer of knowledge and subsequent training continue until all groups have a chance to practice plastic molding processes on appropriate equipment and to produce the specified products. Continuous process improvement is the goal that each group strives for, regardless of their trainer or trainee role. Product outcomes and operational efficiency, measured by process cycle time, are expected to increase gradually as the groups progress, whereas the frequency of avoidable mistakes is expected to decrease. Students are also asked to rate the level of preparation and safety/operations/knowledge transfer ability of their trainers in each lab session with the training component. Note that the very last student group who receives training of plastic molding processes has the opportunity to train a different group of students in the welding lab instead of the plastic molding lab. This instructional model provides all students with equal chances to receive and conduct hands-on training for continuous process improvement in the class.

3.4 Industry Survey

To understand industry's skill and training expectations of our graduates, a survey was conducted among the local companies who typically employ ISyE graduates. The survey was fully approved by the university's institutional review board (IRB). Table 4 lists the questions included in the industry survey along with the intended answer format. Background questions regarding industry classification, number of employees, job role and ISyE graduate hiring experience of the individuals completing the surveys were also included. The purpose of this survey was to investigate industry perceptions of the college academic programs' preparation of ISyE graduates, the importance of hands-on skills, practical continuous process improvement experiences and ability to train others. Industry perception is then compared and contrasted against student perception of similar items to identify any misalignments in job expectations.

3.5 Student Survey

To assess students' hands-on continuous process improvement experiences in the new, integrated manufacturing processes lab model, a second survey (also approved by the university's IRB) was conducted in ISYE 350L class at the end of the semester after the first implementation. See Table 5 for the list of survey questions and their intended answer format. Student demographics,

Table 4. Summary of industry survey question (IQ) regarding the preparation of ISyE graduates for industry

Questions	Answer format
IQ1. Please rate the level of career preparation typically observed in college hires	5-point rating scale: 1 = inadequate, 5 = very well-prepared
IQ2. Please rate the importance of hands-on skills desired in college hires (either software or hardware related)	5-point rating scale: 1 = not important, 5 = extremely important
IQ3. Please rate the importance of college hires having prior practical experiences in continuous process improvements	5-point rating scale: 1 = not important, 5 = extremely important
IQ4. Please rate the importance of your engineers, at any level of their career, having the ability and experience in training others	5-point rating scale: 1 = not important, 5 = extremely important
IQ5. Please rate the importance of your engineers, at any level of their career, the ability and experience in continuous process improvement	5-point rating scale: 1 = not important, 5 = extremely important
IQ6. What are some other critical hands-on skills that are highly desired in college hires?	Short answers

Table 5. Summary of manufacturing processes lab student survey questions (SQ)

Questions	Answer format
SQ1. How would you rate your level of involvement in lab exercises in ISYE 350L this semester?	5-point rating scale: 1 = no involvement, 5 = extremely involved
SQ2. Have you experienced any hands-on continuous process improvement exercises or activities as part of a college course beside ISYE 350L? If yes, in what format? • Software-based exercises/activities • Hardware/equipment-based exercises/activities • Conceptual projects only • Others, please specify	Yes/No answer with more than one answer selection and additional comment options for the follow-up question
SQ3. How valuable was your hands-on continuous process improvement experience in the CNC milling lab?	5-point rating scale: 1 = not valuable, 5 = extremely valuable
SQ4. How valuable was your hands-on continuous process improvement experience in the plastic molding lab?	5-point rating scale: 1 = not valuable, 5 = extremely valuable
SQ5. Did you participate in training another group during either the plastic molding or welding lab? If yes, how valuable was your experience during the training session when you were the trainer?	Yes/No answer with a 5-point rating scale on the answer to follow-up question: 1 = not valuable, 5 = extremely valuable
SQ6. How would you rate the importance of hands-on continuous process improvement experience during your undergraduate study in preparation for your future job after graduation?	5-point rating scale: 1 = not important, 5 = extremely important
SQ7. How would you rate the importance of being able to train others in preparation for your future job after graduation?	5-point rating scale: 1 = not important, 5 = extremely important
SQ8. Do you wish to experience more hands-on continuous process improvement exercises in your courses next year?	Yes/No answer

such as age, gender, ethnicity, major, hometown location, and university admission status (freshman vs. transfer) were also collected as part of the survey. The student major question was included in the survey because the manufacturing processes lab class was also open to students from other engineering majors within the school as a technical elective option.

4. Results and Discussion

4.1 Industry Survey: Preparation of ISyE College Graduates and Industry Expectations

The industry survey was administered through the USD industrial and systems engineering program's advisory board and local alumni networks. Eleven responses were received, among which six companies were in manufacturing, two were in healthcare, two were in defense and one was in software business. 82% of the participating companies reported having more than 1,000 employees in their workforce. The individuals who completed the survey held engineering job titles with or without manager/director/executive labels. All claimed to have had experiences of hiring ISyE graduates within the most recent two years. Table 6 summarizes the numerical responses obtained from the surveyed companies, based on 1–5 Likert-scale type of answers.

Data shows that hands-on skills, ability to train others, and experience in continuous process improvement are strongly valued by companies who typically employ ISyE graduates. These skills and experiences are highly desired not only in recent graduates but also among currently working engineers, evidenced in average numerical responses (IQ2-5) range from 4.36 to 4.82 on a 1–5 scale. However, industry perception of recent college graduates' level of career preparation (IQ1) was rated lower compared to expectations, 3.55 +/– 1.13 on a 1-5 scale. Besides continuous process improvement and training skills, companies listed software, working with data, working with hand/power tools, manufacturing processes, assembly/disassembly principles, troubleshooting problems, communication, teamwork and work-life balance as other critical, highly desired skills in college hires (IQ6).

The result suggests that the skill gap in academic training program for graduates to meet employer's expectations is still prevalent as previously reported by others in the past years [12, 16, 31]. Despite the efforts made by various programs to bridge the skill gap, college graduates still do not appear to fully

Table 6. Summary of numerical responses from industry survey (N = 11)

Survey question	Numerical response average	Numerical response standard deviation
IQ1	3.55	1.13
IQ2	4.73	0.47
IQ3	4.55	0.52
IQ4	4.36	0.67
IQ5	4.82	0.40

meet industry expectations. This could be due to the fast-paced advancement of technologies, the dynamic changes in social expectations, the increasing competition in the global economy and the challenging constraints often faced at academic institutions. Regardless of the challenges, the result from this industry survey reveals opportunities for ISyE programs to better strive for curriculum innovation and student engagement to narrow the skill gap.

4.2 Student Experience of the New Integrated Manufacturing Processes Lab Model

38 out of a total of 48 students who enrolled in ISYE 350L manufacturing processes lab in the semester of study completed the survey (i.e. a 79.2% response rate). Table 7 summarizes student demographics data collected as part of the student survey. International students came from Mexico, Guatemala, Kuwait, Saudi Arabia and Spain. International students accounted for approximately one-third, on average, of the graduates in the ISyE program between 2016 and 2020. The higher international student and transfer student participation in this study was mainly due to the inclusion of several short-term, junior/senior international exchange students from Spain who took the manufacturing processes lecture and lab. Specifically, 13.2% of the survey participants belonged to this group of students from Spain. It is also noteworthy that the percentage of female students included in the study (44.7%) was significantly higher than the female representation in a typical undergraduate engineering major. ASEE reported that women represented 22.5% of all of the awarded Bachelor's degrees in engineering in 2019, whereas 31.2% of the industrial/manufacturing/systems engineering Bachelor's degrees were awarded to women [32]. At USD, female students made up 43% of the ISyE student body on average between 2016 and 2020. On the other hand, 32% of the total engineering undergraduates in the school of engineering at USD were female in 2019. The reason for a higher female representation in our student body could suggest that liberal arts education is more appealing to female students than to male students.

Table 7. Summary of student demographics included in the student survey

Demographic category		**Representation**
Age	18–20	15.8%
	21–23	73.7%
	> 23	10.5%
Gender	Female	44.7%
	Male	55.3%
Ethnicity	White	60.5%
	Hispanic/Latino	18.4%
	Asian	5.3%
	Mixed race of Asian/Latino & White	7.9%
	Others	7.9%
Major	Industrial & systems engineering	97.4%
	Mechanical engineering	2.6%
Hometown location	United States of America	57.9%
	International	42.1%
USD admission status	Freshman	55.3%
	Transfer (including short-term international exchange students)	44.7%

Of all the surveyed students, 47.4% indicated that they experienced some form of hands-on continuous process improvement exercises or activities as part of their previous or current college courses beside ISYE 350L lab class. Half of those students were admitted to the university as traditional freshmen. While 16.7% of the "experienced" students stated that their "hands-on continuous process improvement" experience was drawn from conceptual projects only, a majority of them (72.2%) cited that hardware/equipment and/or software were involved in their prior course activities. Only 11.1% of the "experienced" students cited Legos as their only prior hands-on exposure on this subject. As previously discussed, ISyE students only began taking ISyE-specific major classes in their junior year. ISyE majors, excluding the short-term international exchange students, take the Six Sigma – Process Improvement Methods class (ISYE 335) concurrently with the ISYE 350L class during the second semester of their junior year. Legos were used in ISYE 335 lab exercises. Because no other ISYE classes in the current curriculum used hardware/equipment to teach students continuous process improvement concepts, it is possible that students might have misinterpreted SQ2 question of the survey. Students might have cited their hands-on experiences from the first two courses of the introductory engineering series where they worked with both hardware/equipment and software to learn and practice the engineering design concepts. It may also suggest that students did not have a clear understanding of what "hands-on continuous process improvement" exercises entail when answering this question. A more in-depth set of questions would be necessary in a future survey to help students distinguish their prior experiences with respect to general hands-on skills and continuous process improvement applications.

Table 8 summarizes the numerical responses from the student survey. Students considered themselves to be very highly involved in the ISYE 350L manufacturing processes lab exercises during the

Table 8. Summary of numerical responses from student surveys. (N = 36 for SQ5; N = 38 for all other SQs)

Survey question	Numerical response average	Numerical response standard deviation
SQ1	4.66	0.48
SQ3	4.26	1.00
SQ4	4.39	0.73
SQ5	4.06	1.03
SQ6	4.32	0.90
SQ7	4.51	0.77

semester (SQ1). Students reported very valuable to extremely valuable learning experiences with the new, integrated CNC milling lab and plastic molding lab (SQ3 and SQ4). The new plastic molding lab model was valued slightly higher (4.39 +/– 0.73) compared to the CNC milling lab (4.26 +/– 1.00) by the students, though the difference was not statistically significant. Students might have slightly preferred the practice of identifying areas of process improvement and training others, as in the case of plastic molding lab, over actually executing the ideas themselves, as in the case of CNC milling lab. Students might have also felt more comfortable and less intimidating with others testing out their ideas due to their lack of skill confidence. A more detailed study is needed to confirm any statistically significant differences in student learning experiences between the two pedagogical approaches and the root causes behind the discrepancies. Although the learning mechanism for continuous process improvement was different between the two selected labs, survey data shows positive student learning experiences with the practices of the continuous process improvement concept overall while learning new manufacturing processes and equipment operations.

A higher level of variation in student experiences in the CNC milling lab was also observed. This could be attributed to several factors. Lab instruction was conducted separately by an official lab instructor (i.e. program's faculty) and a lab staff member. Prior to the CNC milling lab, students were taught how to write G&M code from scratch and create a CNC program for a nameplate designed with some personalized features. The programming portion of the lab was handled solely by the faculty lab instructor. After students' CNC programs were verified and approved by the faculty lab instructor, students then proceeded onto the CNC mill where they learned about safety and machine operations from the lab staff member. Although the faculty lab instructor assisted students with their CNC program revision and set lab expectations throughout the CNC milling lab, the lab staff member worked solely with students in the machine shop during the basic run and the continuous improvement run of the lab. This instructional staffing model could have introduced some disconnection in communication, lab expectations and improvement criteria during the lab activities which, consequently, could negatively impact student learning. As a relative comparison, the plastic molding lab was conducted solely by the faculty lab instructor from the beginning stage and throughout the progressive continuous improvement stages. As a result, a lower variation in students' learning experiences were reported. These observations call for a review of current lab staffing model, setting clear outcome expectations for students and further promoting collaborative efforts between faculty and lab staff.

Nearly all students in the lab had the opportunity to practice training their peers using the hands-on continuous process improvement approach (SQ5). The training was done in the plastic molding lab or the welding lab. Students rated their training experience to be mostly "very valuable", with a rating of 4.06 +/– 1.03 (on a 1–5 scale). Student training experiences were not perceived as highly as the continuous process improvement learning, though the differences are not statistically significant. The slight reduction in experience could be attributed to several limitations associated with student training plan implementation during the semester. First, large group size might have downgraded the training experience. Each lab group comprised of four students. The four students in the group could have different training styles. These students attempted to train four other inexperienced peers who could also have different learning styles and preferences. Secondly, both groups were constrained to 170 minutes of lab time to not only teach and learn all they could but also produce multiple products with progressively improved outcomes. Although students were placed in these challenging situations, the constraints could have also pushed students to be more efficient and effective. Lab evidence shows that students were able to test out continuous process improvement proposals from the previous groups, avoid the same mistakes and progressively produce better product quality. It was also observed that students had limited time to work on a team training plan prior to the lab due to multiple pre-lab assignments (e.g., lab reports, training plan, pre-lab quiz, safety test and reading). A less heavy workload and fewer deliverables could help students focus more on the team training strategy and learning effectiveness, thus improving student learning experience.

Result shows that 89.5% of the surveyed students wished to have more hands-on continuous process improvement exercises in their major curriculum (SQ8). This outcome encourages the continuation and expansion of the new integrated curriculum and instructional pedagogy model in which students apply cross-cutting ISyE concepts while acquiring new knowledge within the discipline. It is noteworthy that 75% of the students who did not express the interest of having more continuous process improvement experience in their major curriculum were international students, regardless of their country of origin. This observation could be attributed to the differences in career paths of international versus domestic students. Domestic ISyE graduates at USD typically end up working in industry located inside the United States of America, whereas international graduates, especially the Middle Eastern graduates, often pursue more business and management-oriented career paths. For example, based on the published data for 2015–2020 USD graduates, half of the Middle Eastern ISyE graduates ended up working in a financial or management company after graduation, whereas 98% of the domestic graduates were employed in an engineering-focused company [33].

4.3 Student Perception of Industry Skill Values and Expectations

Students were asked to rate the importance of hands-on continuous process improvement skills and ability to train others as a preparation for their future career. Data shows that students perceived a very important to extremely important value in hands-on continuous process improvement training towards future job and career preparation (SQ6, ratings of 4.32 +/– 0.90 on a 1–5 scale). Similarly, students thought the ability to train others as another highly important skill to have in preparation for their employment after graduation (SQ7, ratings of 4.51 +/– 0.77 on a 1–5 scale). Students' perception of these two valuable skills are statistically comparable to the skill expectations derived from the industry survey outcomes (see Table 6, IQ4 and IQ5). However, it was interesting to note that students perceived a higher value for the "ability to train others" compared to the "hands-on continuous process improvement" skill, whereas industry expectations were reversed. The results from both industry and student surveys suggest that there may be some mismatch between student perception of the skills they need for their jobs and the skills that are actually desired by the employers. To help resolve the mismatch of perception and expectations and to bridge the gap between academic training program and industry needs, a more in-depth industry survey should be conducted once every few years to re-assess skill demands in college graduates. A wider range of industry stakeholders, including different industry types and locations, would produce a stronger and more representative data conclusion. However, it would be more beneficial towards specific program curriculum improvement purposes if the survey is discipline-specific to avoid a generalization of skills and expectations.

5. Conclusions

An industry survey to local employers shows that hands-on skills, ability to train others and experience in continuous process improvement are highly valued by companies who typically employ ISyE graduates. However, industry perception of recent college graduates' level of career preparation was rated lower than expectations. To bridge the academic training gap in our graduates, a new integrated manufacturing processes lab model was implemented in the ISyE junior curriculum. Students were provided the opportunity to apply and practice continuous process improvement concepts through hands-on learning of different manufacturing processes and machine operations. Students reported positive learning experiences in the new lab model when the continuous process improvement concept was practiced through the testing and implementation of their own ideas or when training others to execute the proposed improvements. Student perception of the importance of hands-on continuous process improvement skills and the ability to train others were also assessed. Overall, students perceived a similar level of importance for those job skills in comparison to industry. However, students' value rating of each skill appears to mismatch with industry needs.

The results from this study show positive outcomes from the implementation of the new integrated manufacturing processes lab model in the ISyE program. This study provides clear answers to the original research questions. First, it is quite feasible to integrate the teaching of manufacturing operations and hands-on continuous process improvement practices in an undergraduate industrial and systems engineering curriculum. Second, student learning experience of fundamental manufacturing operations principles were not compromised with the integrated instructional model. Third, there is some mismatch between industry needs and student perception of skills employers are looking for in recent industrial and systems engineering graduates. The insights obtained from this study also help identify several areas of curriculum improvement in the program, including student workload expectations, instructional staffing, and skill gap bridging. The new integrated instructional model could be further improved and expanded throughout the curriculum to provide students with more hands-on cross-cutting skills and bridge the gaps between academic training and industry expectations.

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