Student Outcomes: Improved by External Assessments?

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Abstract

Background

We evaluated the effect of using a globally recognized professional certification exam as an external assessment of the effectiveness of an engineering course in addition to student perception surveys of teaching effectiveness.

Purpose/Hypothesis

To identify the impact of knowledge of subject matter independent of the institution and instructor by use of an external professional certification exam at the end of each semester.

Design/Method

The sample of the study consisted of 479 students enrolled in a lean manufacturing course at a large public research university in the central United States from Fall 2016 to Spring 2020. Students were actively encouraged by extra credit points to take the Lean Knowledge Certificate offered by the professional society SME during the final week of each semester.

Results

Findings suggest that students increasingly see the value in seeking professional certifications since there is an upward trend in the number attempting the certification. Additionally, more students are passing, gaining professional certification in the process. They are learning the material irrespective of their feelings about the instructor.

Conclusions

While establishing academic learning objectives is clearly a requirement, institutions should consider whether the course objectives and associated materials can be aligned with the body of knowledge of industry professional societies certifications to ensure that the knowledge gained in a course can be readily applied to a career in industry.

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1.0 Introduction

Academic institutions at all levels strive to ensure the competency of their graduates by a variety of means, including measuring course learning objectives and conducting assessments. Outcome based education (OBE) is a critical educational development [1], employing both traditional assessment methods of homework, quizzes, exams, and papers throughout each term as well as newer paradigm techniques of flipped classrooms and PBL projects which are transforming curriculum and students alike [2].

Furthermore, the competency of the institution, particularly at the tertiary university level, may be directly or indirectly measured by national and international rankings of the entire institution or of academic units therein, such as a college. ABET assists with ensuring competency of institutions on a global scale by ensuring minimum levels of preparation of qualifications for industry [3].

Likewise, one may estimate the competency of faculty within an institution by their individual academic credentials, number, or amount of grants as well as the number of conferences and peer reviewed articles, citation count of each article, or the impact factor of the journal in which the articles are published. While it certainly has its own concerns, the h-index is still the most common measure of an individual researchers measure of both citation impact and productivity [4]. Next, for an individual student one may determine competence by combined information of their degrees, the awarding institutions, and the grade point average (GPA) for each degree [5]. How can industry compare engineering graduates from different institutions in different countries, much less different US states? We suggest that professional certification exams offer a means to compare students and institutions on specific sets of skills need to perform the requirements of a particular job. Moreover, we suggest that this comparison can be performed regardless of how students "feel" about the course, the instructor, or the institution. While the literature is clear that student outcomes are enhanced when they like and trust their teachers [6], it would be naïve to assume that if a course had 100 students that each student would "like" the professor. Kindness and compassion should be encouraged, but direct feedback may be far more helpful to our professional growth and development, even if it does not feel good to receive, for accepting criticism is difficult [7].

1.1 Background

1.1.1 Government licensure. Laws related to industry specific licensure are established by the Government to ensure public safety. State and federal licensure require both formal knowledge and experience ability are clearly documented prior working to in certain fields, such as the National Council of Examiners for Engineering and Surveying (NCEES) for Professional Engineers (PE) [8]. Yet even with government licensure requirements, there can be drawbacks. Many individual government entities, such as US states, have different requirements in medicine, law, and engineering related to the formal education requirements of individuals. Some states allow for associate's level when other require bachelor's degrees as part of licensing [9]. Moreover, many states allow engineering technologists to sit for PE exams, while another does not, noting differing requirements of technologists compared to engineers. For example, Kansas says: "An engineering technology degree does not meet the educational requirements" [10].

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1.1.2 Industry certifications. Various professional societies recognize individual experience and knowledge in specific domains, such as the SME, a nonprofit association of professionals, educators, and students in various manufacturing related industries and functions. This sentiment is echoed by ABET which states that professional certifications "can provide feedback on the knowledge transfer that occurs within academic programs" [3]. Additionally, professional certifications serve as professional standards, by baselining the capabilities and competencies of students, which are needed to help improve both the reliability and validity for studies on engineering education [11].

1.1.3 Academic learning objectives. We know that classroom teaching styles and methods influence how students are taught, including, but not limited to, 1) the rate of progress through each topic; 2) the sequence of these topics; and 3) the manner, frequency, and duration of assessments. With respect to the third element, these terms are referred to as "Washback" or what happens in the classroom as result of an assessment [12].

Studies indicate that modifications to methods of teaching and adding stylizes elements to the topics of a course, in and of themselves will not enhance Engineering Education. Instead, what is needed is a change in culture [13]. Yet cultural changes take time to transition and only with consistent connection with their craved condition. Without consistency over time, the gap between professional practice and student scholarly skills will continue to grow as it has for generations [14], [15].

However, course learning objectives must link to industry needs, regardless of the teaching style used. At the subject institution, several Industry Advisory Board (IAB) members informed the department and college of their dissatisfaction with the readiness of graduates to be impactful quickly after joining their firms. This was voiced despite the existence courses being taught for many years with clearly stated learning objectives. As the stakeholders who provided jobs to graduates these comments were strongly considered. When similar statements were voiced by top executives from large employers in the community, namely aerospace, energy, and agriculture, inactive could be disastrous. These remarks from the institution's IAB mirror the findings from higher education studies in the United Kingdom, where employers sent a "clear mandate … to focus on outcomes and links more closely with employability [16]."

1.2 Best Practices

1.2.1 Project Baseline learning. More studies suggest the need for collaboration between academia and industry, specifically using project based learning (PBL) where the curriculum allows students to apply their knowledge in industrial settings [17]. PBL is a pedagogical method which places students at the core of the classroom experience believing students obtain greater knowledge solving real world problems. While we agree, real-world projects may not be feasible for class sizes of 75+ students. Furthermore, when large numbers of the students are international, the number of project options may be limited by industry.

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1.2.2 Professional certifications. Researchers state that professional association certifications are increasingly being added to engineering curricula as a basis for guiding improvement and relevance of courses [18]–[20]. Given the frequency and number of such analysis, our study focuses on this element of academic-industrial collaboration.

1.3 At Study Institution

1.3.1 Wichita State University. In the College of Engineering, two engineering departments have openly encouraged students to seek industry certifications for well over a decade. These are engineering technology (ENGT) and industrial, systems, and manufacturing engineering (ISME). In the late 2010s, the ISME Department added professional certifications as a condition for graduation [21]. However, only in courses specifically taught by one of the authors were students able to gain certifications during the same semester of the courses.

1.3.2 ISME. Within ISME, a systems engineering course launched initiatives to align with professional certification requirements. It aligned with the International Council of Systems Engineers (INCOSE)'s Body of Knowledge (BOK) since 2016. Research shows that courses that include both the theory of a topic and application exercises are preferred. When the application of knowledge is enabled, retention is improved. Additionally, when knowledge can be linked to professional development like passing professional certifications, it is beneficial [22].

Despite years of encouragement, student participation in the INCOSE Associate Systems Engineering Professional (ASEP) exam had been limited, typically one student per semester. Prior to summer 2022, students had to individually register via Prometric. Since there was typically a three-month backlog, students were unable take the certification during the course semester. Without being able to schedule within the course semester, the extra credit incentive for students was eliminated.

Beginning in Fall 2021, the instructor became full-time faculty at the institution. This status change granted time to contact INCOSE in advance of the semester, ensuring a proctored exam could be held during the semester. In the last week of the semester, twenty-six of the thirty-eight students or sixty-eight percent were registered for the INCOSE ASEP exam. Despite only six passing the certification, this is a positive outcome. Although the course had been revised each year, those years had only one student registered so the updates were based on a small sample size. While feedback was not enjoyable for students, because it was not kind, the data from students failing the certification exam was far more valuable to improving the course than from kind, positive passing results [7].

1.3.3 ENGT. In addition to the PBL efforts throughout students' undergraduate experience, there is a multi-pronged approach linking academic learning to industry expectations in ENGT. First, professional certifications directly from industry firms already occurs. Second, professional certifications will be piloted in Spring 2023. Lastly, the LL certificates of completion enable students to broaden their knowledge while simultaneously allowing students to build their personal brand by posting certificates on LinkedIn.

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A course on programmable logic controllers allows students to satisfy the institutional learning objectives while simultaneously obtaining the ABB Robotics SMART Certification for STEM Programming [23]. Additionally, the institution piloted materials offered by Microsoft, such as Data Analytics via PowerBI. Although Microsoft materials have been implemented into existing courses, no student attempts at certification have yet occurred. Finally, gap analysis of three courses compared learning objectives and the associated certifications BOKs. We will launch three professional certifications in 2023, including SME's Certified Manufacturing Associate for sophomores, SME's Certified Manufacturing Technologists for juniors, and the NCEE's Fundamentals of Engineering exam for seniors.

For broad-based business processes knowledge, several courses have incorporated linkedin learning (LL) courses, such as "Operations Management Foundations" for intermediate design. ENGT encourages certificates of completion by using LL instead of textbooks or as extra credit. Researchers indicate LL is recognized globally as an effective learning platform [24].

1.4 Theoretical Framework

Epistemological foundations for our study are the tenants of lean [25], specifically those noted in the MIT study of the Toyota Production System (TPS) in the "The Machine that Changed the World" and "Lean Thinking, Banish Waste and Create Wealth in Your Corporation." The five principles of lean, value, value stream, flow, pull, and perfection serve as the foundational branches of the course on which other techniques are expanded [26], [27].

1.4.1 Application of the theoretical framework

1.4.1.1 Value. According to the Lean Enterprise Institute (LEI) [28], founded by James Womack and Daniel Jones, Value can only be defined by the customer of a given product. While students are the customer of the institutions, the ultimate customers are employers.

Since the IAB represents the customers who said our students were not prepared, we needed to act. However, we needed specific requirements to which we could design, build, and test. We opted for the SME Lean Knowledge Certificate and its BOK [29].

Having translated the external stakeholder requirements to our internal ones, objective criteria was established. A gap analysis could be performed from the legacy materials and the BOK [28]. Additionally, this review was conducted annually using each cohort's certification results.

1.4.1.2 Value stream. The Value Stream is, according to LEI [28], all the steps necessary to convert raw materials to finished goods ready for the customer. Table 3 shows our steps during Spring 2022. The activities of each class day are scheduled in detail to ensure visible management of all activities by students, the teaching assistant, and the instructor against a documented standard of work.

The primary method of embedding the lean principles into the course was through repeated iterations of the Deming PDCA Cycle, based on the earlier PDSA cycle of Walter Shewhart [30], [31]. This simple project management tool is practical, generating efficient and effective

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improvements to any process, whether preemptive preventive action or re-active correction action [32].

1.4.1.3 Flow. Flow, according to LEI [28], strives to remove all problems within process steps ensuring easy value stream movement. In this flow river, the eight types of waste are rocks hidden under the water level of inventory [33].

Specifically, we created standards in our assessment instructions, rubrics, lecture schedules, and lecture materials. This included a daily "Foundation" of the 5 lean principles ensure the benefits of repetitive practice, yet in different formats to ensure student engagement.

1.4.1.4 Pull. With respect to pull, LEI states that customers should be able to "pull" the next product when desired rather than it being "pushed" on them from inventory stockpiles [28]. While we did not directly allow a large class of students to work self-paced, we migrated our materials to modular mini-lecture of 25 minutes so that topics were easily moved based on external variability, such as mid-western winter storms. Furthermore, we plan to further shorten each to ten minutes to enable a YouTube channel.

1.4.1.5 Perfection. Finally, LEI states that to achieve Perfection lean process improvements need to be infused into the organizational culture [28]. Given that we have sustained incremental changes to the course from 2016 to 2022, we are pursuing Perfection.

1.4.2 Course instructional design. This paper compared traditional learning objectives and topics of the course with the SME BOK. This is like the "analysis of inconsistencies" of other studies where educational and professional standards are compared [34]. The resulting gap launched a series of semester-long case studies using the PDCA model. Annually, adjustments were made to the course, reducing the gap from the current to future state.

1.5 Problem Statement

This study addresses the industry need for student competency by ensuring alignment between societies BOK and institutional learning objectives. Specifically, the professional certification exam served as an external assessment, allowing for repetitive benchmarking via the PDCA model with continued re-calibration of the course effectiveness.

1.5.1. Research questions. We used the FINER criteria to determine the key aspects of our research question and the PICO(T) approach for the same research question [35], [36]. The FINER criteria are an acronym representing the words "feasible," "interesting," "novel," "ethical," and "relevant." Likewise, PICOT is an acronym for population, intervention, comparison group, outcome of interest, and time. To identify the impact of our strategy, we sought to answer the following research question:

RQ – Does the student passing rate of a professional certification change based on the modifications to the course following the review of each previous external assessment results?

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1.5.2 Hypotheses. We did not have a specific "null" hypothesis as suggested by researchers, because the authors began our study as adjuncts and teaching assistants, respectively, and were not fully versed in the scientific method [36]. The researchers attempted to make the RQ falsifiable despite the lack of a formal statistical test to determine support for or rejection of our RQ.

By data tracking, showing course schedule modifications, and cyclic use of the PCDA model in each cohort case study, the desired future state of the BOK is repeated for the current researchers and reproducible for all others. The future state includes a) active learning; b) the BOK; and c) textbook; and d) mobile application, which are referenced regularly in this study.

In Section 2.0, methodology, we describe the methods, materials, and data used in our study. Section 3.0, results, presents the data of our study from text to tables, charts, and graphs. Next in Section 4.0, analysis, we methodically examine our results in detail for the purpose of interpreting them. Moving to Section 5.0, discussion, we discuss the results and analysis of our research study, explaining them in the broad context as well as comparing our findings to those in the literature. Section 6.0, implications, considers the implications of our research study across three (3) realms: 1) academic, 2) industry, and 3) government. section 7.0, conclusions, summarizes the key findings of the study. Section 8.0, limitations, and Section 9.0, future work, explore the restrictions of our research study and the suggested areas of research to further related research questions, respectively.

2.0 Methodology

2.1 Concept

The PDCA iterative life cycle model was applied to a graduate engineering course on continuous improvement, IME 767, Lean Manufacturing, using professional certification as an external assessment during each check cycle.

2.2 Participants

This research study is a records-based review of data collected over several semesters from 2016 to 2022 at Wichita State University in Wichita, Kansas. Specific student demographic was not gathered as the instructor was an adjunct and did not consider such aspects as there was no requirement for or expectation of research studies of the adjunct position.

2.3 Development

2.3.1 Informed consent. The Institutional Review Board (IRB) process at the study institution was undertaken. This first included the submission of an IRB Determination Form to allow the IRB to rule if our research study would be classified as exempt or not. The IRB determined that our study was determined to be exempt through the non-convened review mechanism as this was primarily a "Records review study" of former students results from an external professional associations record.

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During each specific cohort semester, students individually authorized SME, in writing, to share their certification results with the course instructor. Since demographic data was never captured and all the results have been de-identified, we are confident that no FERPA or HIPPA related data of students could be misused. Final IRB of our study was hence obtained as exempt.

2.3.2 Information. Throughout each cohort semester, students were repeatedly explained, both verbally and via presentation slides, the certification process, the format of the SME exam, and associated costs, and voluntary nature of the participation, as well as the incentive of extra credit points and the fulfilment of ISME department degree requirements. Furthermore, the researchers frequently illustrated on presentation slides, specific job opportunities that required or preferred the SME lean certification.

2.3.3 Comprehension. While the researchers did not specifically ask each student if they understood the process, we have several proxies that we believe illustrate each students understanding. We never had full participation, thus, we concluded that students understood the voluntary nature of the certification. Students had to register with SME outside of class, remotely, willingly provided contact and payment information at a time and place of their choosing. Finally, the researchers deduced that students enrolled in a graduate engineering course possessed the mental faculties to understand, weigh the costs and benefits, and comply with the voluntary process.

2.3.4 Voluntary. As previously stated, the students opted, voluntarily, to participate in the external assessment of SME. While the percentage of students attempting the certification continued to increase, the never reached full participation.

2.3.5 Study design. This research study was a record based of results of a professional society's BOK via their certification exam. Specifically, the Lean Knowledge Certificate, itself part of the bronze level of certification from SME, was incorporated. The SME certification exam served as an external assessment of our curriculum and our students' understanding of the lean BOK. SME's certification exam was selected as the external assessment because of the strong relationship between the legacy course materials and stated learning objectives of the lean course [37].

2.3.6 Human subjects. Because this research study is records review, the subjects are not formally classified as human subjects. Recently, the researchers had been trained in the application of the Belmont reports on ethical principles of research involving human subjects. Specifically, the principles include 1) respect for people, 2) beneficence, and 3) justice [38]. The researchers are confident that we behaved ethically in the past with students when their data was passively being collected during our status as adjunct and teaching assistant as is discussed next.

Regarding the ethical research principle of respect for people, the students clearly are a vulnerable group based on their status as university students. However, this institution vulnerability was mitigated as none of the students was "coerced" to participate in the SME certification exam. While the participant rate continued to increase, it was never full participation. We did "induce" the students with the extra credit points if the passed the SME certification, but they were other free, on campus extra credit opportunities throughout the

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semester so the SME certification was not unique in that matter. For the ethical research principle of Beneficence, the researchers were able to maximize the benefits to the students, the institution, and our industrial partners with no harm to the students. Finally, since all students in the course were allowed to voluntarily participate in the external assessment, the ethical research principle of Justice was upheld. US and foreign nationals, men, and women, and participation of various racial and religious traditions, illustrate the inclusive nature of the study. Thus, all had benefited from the SME assessment. Moreover, since the certification exams were always held on campus at the study institution the concept of convenience was secured.

2.3.7 Data management plan. From the collected data, we performed a survey for those students who participated in the professional society exam (external assessment). This survey was brief but related to the two of the three categories we have devised, namely, BOK and assessment delivery. For the BOK category, the reflection questions we incorporated in the survey was whether the students had read the required textbook from that professional society. Regarding the assessment delivery, the survey sought to find the answer for whether the students used a recommended mobile application containing practice questions. The assessment delivery category was not limited to the external mobile application for it also evaluated students regarding the difficulty level of the professional certification exam compared to their course quizzes and exam materials.

Separate from the external assessment, there was an active learning category, as much like PBL as could be achieve with consistently large classes. This category included physical, in-class simulations such as drawing a simple fish with a group of people to illustrate the concepts of standard work or rolling dice and placing them in containers to illustrate process variability and the benefits of lot size reduction and pull systems to facilitate flow. Over the span of three (3) years of research related to these active learning simulations, the researchers increased the frequency and duration of the simulation activities.

2.4 Validity, Reliability, and Trustworthiness

2.4.1 General. The researchers ensured the needs of the various stakeholders, including the students, the academic institution, and our industrial partners were met by following the methods: a) ensuring the verification & validation of requirements; and b) enabling the repeatability & reproducibility of the study.

2.4.2 Verification and validation. The study can be verified by comparing the detailed course schedule, textbook, and lecture slides with the institutional learning objectives and the BOK. Together, these serve as objective evidence that each element of the institutional learning objectives and the SME BOK has been fulfilled by the course materials [39]. Validation, likewise, can be readily traced to the stated needs of the industrial partners. Again, clear objective evidence exists to clearly illustrate that the industry stakeholder requirements are being taught all the relevant subject matter, irrespective of the views of the instructor, the institution, the state, or the nation of instruction. The material covered is appropriate, consistent, and relevant to a BOK managed globally by the professional association [39].

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2.4.3 Repeatibability and reproducibility. If we view the course as the subject of our analysis, with the students as measurements within that "subject," to describe repeatability as Bland & Atman suggest [40], then, our study repeatability is high because the method of assessment, the SME certification exam, was consistent over years, although the course itself changed from 2016 to 2022.

With the same test, offered in the same location on campus, with the same time duration, number of questions, question format, and just before finals each semester, the researchers provided a stable environment for the external assessment, making it highly repeatable. With the detailed description of our methods and materials, other researchers should be able to reproduce our results via direct replication as suggested by the Open Science Collaboration [41].

3.0 Results

RQ – Does the student passing rate of a professional certification change based on the modifications to the course following the review of each previous external assessment results?

Table 1 shows the results of the class improvements that were gradually implemented. These improvements in response improved student performance. There is an increase in number of students from the Fall 2018 to Fall 2019. Usually, the summer enrollments are not comparable to the fall semester. However, due to the accessibility restrictions, we could not provide an overall departmental data. In the table below, the number of students who enrolled in the course and the number of students who participated in the professional certification exam is provided. To understand them in relative terms, there is a percentage data provided that is the ratio of respective student numbers. Passed on the first attempt and second attempt is cumulated in calculating the passing ratio. Passing ratio shows a gradual improvement in the number of students passing the professional certification exam overall with 100% being the best possible outcome.

Table 1. Student data that is not personally identifiable but a collection of numbers that portray the results in professional certification exam over a 3-year period.

Semester	**No. of students**	**No. of students took lean bronze**	**% Of students took lean bronze**	**Passed on first attempt**	**Passed on second attempt**	**Passing ratio**
Fall 2018	56	30	53.57	8	2	0.33
Fall 2019	63	35	55.55	9	7	0.45
Summer 2020	36	17	47.22	12	4	0.94

Figure 1 shows the gradual improvement of passing ratio due to the incorporation of different learning methods. In the fall 2018 the ratio that was 33% which improved year over year in 2019 and 2020 resulting in 45% and 94%, respectively. In the year 2020, the course was offered in the summer semester. Instructors played no role in determining which semester the course is offered. That decision is independent of instructors' abilities.

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4.0 Analysis

4.1 GENERAL

The SME Lean Knowledge certification exam yielded a score for each participant, which was used for the data analysis. The data was analyzed using Microsoft Excel. The researchers confirmed that the data satisfied the assumptions for homogeneity, independence, and normality.

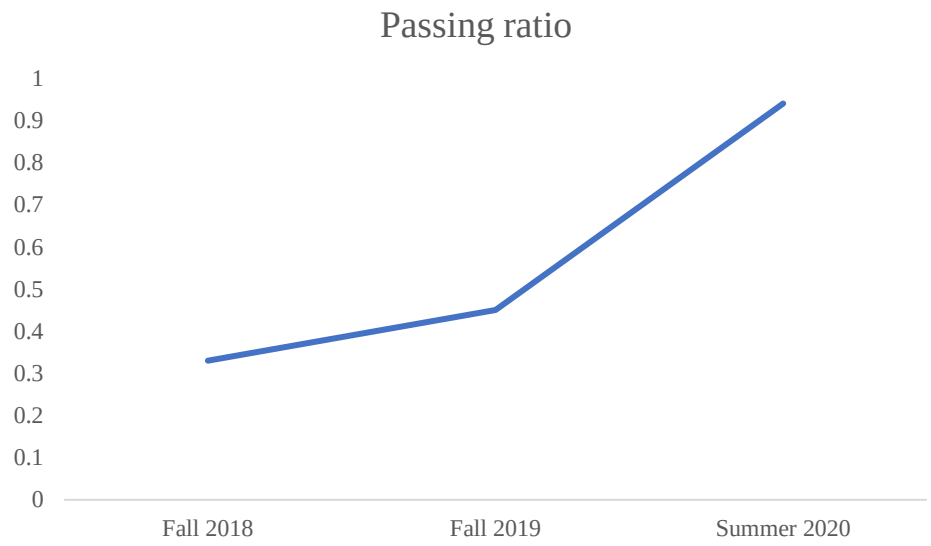

Fig. 1. A visualization of passing ratio improvement over the span of three years.

Beginning in Fall 2018, the researchers asked two questions of each student. These questions were related to the BOK and asked as student departed from the SME certification exam:

Did you read the required course textbook?
The Lean Handbook: A Guide to the Bronze Certification Body of Knowledge

Did you use the suggested external mobile application?
Lean Bronze by Upwardpro.com

4.2 Textbook

For the standardized book question, out of the thirty students, eight students mentioned that they had not read or reviewed a standardized book. That means that there were twenty-two students who read the book. If we take the ratio of students who read the book in 2018 to the total number of students participated in the exam, it comes to 73.33% and the remaining percentage which is 26.67% did not read the book. Let us consider that the ratio for students who passed the exam to the ones who read the book, which was 45.45%. Most strikingly however is that fact that every student who read the book, passed the certification exam. This showed that reading the required

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course textbook played a role in helping students pass when compared to those who did not read the book. It is well established in the literature that reading skills can be improved by using either the PARROT or SQ3R reading strategies [42]. However, the one thing that is not addressed in any reading strategy is the obvious fact that the material itself must read.

4.2. Mobile application. Similarly, for Fall 2018, if we consider the statistical analysis for the students who used an external mobile application that provided students with practice questions for the certification exam, the numbers follow a similar pattern to that of the Textbook. 100% of those students who passed the exam had used the mobile application compared to those who did not us it for practice. Unlike the textbook case, the students who used the mobile application did not necessarily pass the certification exam. Since the mobile application was the only one of its kind, alternative sources could not be evaluated. However, the research is aware that issues like service quality, system quality, and content quality are significant factors to the success of mobile applications success in higher education [43].

5.0 Discussions

5.1 General

As we begin our discussion of the study's impact, we first remind the reader of our RQ:

RQ – Does the student passing rate of a professional certification change based on the modifications to the course following the review of each previous external assessment results?

We can clearly see the correlation between the number improvements of the course of over the years and the positive student outcomes on the external assessment, the SME Lean Knowledge Certificate. These improvements can be categorized into three (3) areas, namely active learning, body of knowledge, and specific improvements derived by the data of the collective results of each student cohort that attempted to external assessment.

5.2 Active Learning

Active learning methods have much greater impact in engage students with the material when compared to traditional methods [44]. Thus, the researchers were not surprised that the in-class simulations enhanced the understanding of the concepts. The ability of students to participate in real life scenarios via simulations involved simultaneous immersion in the material and interaction with their peers, performing tasks that they may never have been exposed to otherwise. These real experiences deepen understanding and ability to answer questions both in the assessments of the course, whether quiz or exam, but also those of the professional certification exams.

5.3 Body of Knowledge

Aligning the course to the professional association's BOK reduced and clarified students' preparation materials. The legacy number of books was reduced from a combination of four books, two required, one recommended, and one optional, to a single required textbook. Students

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were able to focus on the concepts globally relevant of Lean Manufacturing. Additionally, the researchers adjusted each day's lecture to maximize the understanding, by slowly building up the layers of knowledge.

While SME administers the BOK and certification exam, four professional associations coordinate to ensure the continued global relevance of the subject matter that comprise the Lean BOK. Collectively, these non-profit organizations make up The Lean Certification Alliance [45] and include A) SME, 2) American Society for Quality, 3) Association for Manufacturing Excellence; and 4) the Shingo Institute.

Our textbook is *The Lean Handbook: A Guide to the Bronze Certification Body of Knowledge* [46], [38]. The handbook has four modules, including

Module 1, Cultural Enables
Module 2, Continuous Process Improvement
Module 3, Consistent Lean Enterprise Culture
Module 4, Business Results

The researchers grouped the course into two parts: Part 1) "Know Why" and Part 2) "Knowhow." Modules 1, 3, and 4 make up Part 1, addressing cultural aspects of establishing and maintaining a lean enterprise and operational metrics and expectations of Lean organizations. One aspect that was added by the researchers to Module 4, which is not directly covered in either the ASQ Handbook or the SME BOK, is related to the primary financial documents of any organization, namely: 1) the income statement, 2) the balance sheet, and 3) the cash flow statement. During the timeframe of the study 2016 to 2022, none of the 479 had any prior knowledge of any of these financial documents, prior to the class. Part 2 was solely geared to Module 2 and the tools and techniques of Lean needed to successfully conduct Kaizen improvement events with lasting impact.

Besides the BOK content, SME influenced two other aspects of our course, specifically, percentage of the BOK and SME proctoring. Using SME materials, we ensured that BOK topics were covered as well as the appropriate frequency and duration of time relative to the BOK percentages. Thus, while Part 2 contains only one module, that module was sixty percent (60%) of the sixteen (16) week semester. Second, SME proctors were used for each cohort professional certification exams. Additionally, all SME certification exams were offered on the Wichita State University campus at least once every semester, although typically twice.

5.4 Improvements from the External Assessment

At the beginning of each semester of the course, a new PDCA case study was initiated based on the previous cohorts results from the SME certification exam. Table 2 summarizes each case study, including: the year, semester, modality, instructor status, teaching assistance textbooks, lecture structure, delivery method of assessments, term paper/project or not, and SME lean bronze certification test offered or not. The italicized fonts in each column indicate changes during a given cycle, for example, on-line format of 2020 because of Covid-19 pandemic.

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Table 2. Course case studies (PDCA iterations) by year.

KEY	YEAR	SEMESTER	MODALITY	INSTRUCTOR	REQUIRED	SME MODULES	QUIZ / EXAM	TERM PAPER	PROJECT	BRONZE	OTHER
A	2015	Fall	Face to Face	Full-Time	Lean Thinking & Learning to See	M2	Paper, short answer, matching, fill in the blank	Individual: Separate article reviews	***YES***	NO	N/A
B	2016	Fall	Face to Face	Adjunct	REQUIRED: Lean Thinking & Learning to See RECOMMENDED: Gemba Kaizen OPTIONAL: Lean Production Simplified	***M 1, 2, 3, 4***	Paper - M/C - 4 options	Team (2-3): journal literature review (5 articles / student)	NO	***YES***	Foundation, Tours
C	2017	Fall	Face to Face	Adjunct	REQUIRED: Lean Thinking & Visual Management (VSM); RECOMMENDED: Gemba Kaizen; OPTIONAL: Lean Production Simplified	M 1, 2, 3, 4 +	Paper - M/C - Length, Tense, remove "Except"	Team (2-3): journal literature review (7 articles / student)	NO	YES	Mini Lectures: 3x 25 Minutes, Reduce wasted slides
D	2018	Fall	Face to Face	Adjunct	***The Lean Handbook: A Guide to the Bronze Certification Body of Knowledge***	M 1, 2, 3, 4 +	***Electronic M/C - SME Style, Takt time 1 minute***	Individual: journal literature review (9 articles / student)	NO	YES	***In-Class Simulations*** , In-Class Videos of Kaizen Events
E	2019	Fall	Face to Face	Adjunct	The Lean Handbook	M 1, 2, 3, 4 +	Random order of Questions, Random Order of Answer options	Individual: journal literature review (7 articles / student)	NO	YES	***In Class Calculations*** , Industry Guest Lectures
F	2020	***Summer***	***On-line***	Adjunct	The Lean Handbook	M 1, 2, 3, 4 +	Forced Completion	N/A	NO	YES	COVID-19
G	2021	Spring	Hybrid	Adjunct	The Lean Handbook	M 1, 2, 3, 4 +	Reviewed questions for format	Individual: journal literature review (7 articles / student) ***McKinsey & Company technology trends***	NO	YES	TUESDAY: Face to Face - Quizzes, Simulations, Calculations, Guests; THURSDAY: Lectures remote (asynchronous)
H	2022	Spring	Hybrid	***Full-Time***	The Lean Handbook	M 1, 2, 3, 4 +	Added 20% more questions	Team: Book Sub-chapters	NO	YES	Micro Lectures: 7x 7-8 minutes to ready for YouTube channel

A	*BASELINE - Lectures: Module 2 only (50% BOK) & Project: Plan only, no Install - Adjunct estimates as TA & Student prior to 2016*
B	*ITAR - International students make industry projects unsustainable for Adjunct*
C	*MODULE 4 PLUS - Financial Statements - Income Statement, Balance Sheet, and Statement of Cash Flows*
D	*SIMULATIONS - Cells / 1 Piece (Tennis Ball), Standard Work (Draw a Fish), Lot Size Reduction (Dice in Tray), 5S (Playing Cards)*
E	*CALCULATIONS - Takt Time, Total Lead Time, Value Added %, Number of Operators, OEE %*
F	*COVID 19 - Removed Module 4, Financial Statements lectures, and Paper given reduced summer semester length*
G	*MCKINSEY & COMPANY - Industry 4.0 Relevant topics CHART "Technologies trends and underlying technologies"*
H	*WSU LEAN BOOK - Standard Work: Student teams write two page sub-chapters*

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Table 3. Semester-long course schedule, aligned to SME BOK.

WK	WK	WK	WK	WK	5:35 - 5:50	5:50 - 6:10	6:10 - 6:30	6:30 - 6:50
	QUIZ - Multiple Choice	**Topic A**	**Topic B**	**Topic C**	**Topic A**	**Topic B**	**Topic C**	**Topic D**
1	Course Overview	History of Lean	5 Principles & 8 Types of Waste	*INDUSTRY* - BOEING - Co-Op	*INDUSTRY* - HP Greely, CO	Kaizen Event - Schedule	Kaizen Roles	Baldrige and ISO 9000
2	Quiz 1 - Waste & Kaizen	*SIMULATION* - TENNIS BALL	Foundation 1, Tools Summary	Roadmap, Certification	Lean Gurus - Overview	Shewhart and Deming	Juran and Ishikawa	Crosby, Feigenbaum, Taguchi
3	Quiz 2 - Gurus	*SIMULATION* - DICE	*PBL* - Project / Paper	M1 - Principles	M1 - Lean Culture - Processes	M1 - Lean Culture - Practices	Cross Train	Empowerment & Collaboration
4	Quiz 3 - SME Module 1	*SIMULATION* - FISH	M1 - Team Basics & Roles	M1 - Team Formation & Dynamics	**EXAM 1**	**EXAM 1**	**EXAM 1**	**EXAM 1**
5	Exam 1 Results	Extra Credit - Options	*PBL* - Project	*PBL* - Paper	M3- Principles	M3 - Processes	M3 - Practices	M3 - Practices
6	Quiz 4 - SME Module 3	M4 - Income Statement	M4 - Balance Sheet	M4 - Cash Flow	M4 - Principles	M4 - Measurement Systems	M4 - Key Lean related Measures	M4 - Key Lean related Measures
7	Quiz 5 - Metrics & Statements	*SIMULATION* - CTQ - Coffee	CTQ (Critical to Quality)	Kano Model	QFD	3P Method	7 Quality Tools	7 Management Tools
8	Quiz 6 - Value	SIPOC, Swim Lane	Flow Chart / Process Map	VSM & *CALC* - Takt Time, Lead Time	**EXAM 2**	**EXAM 2**	**EXAM 2**	**EXAM 2**
9	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***	***SPRING BREAK***
10	Quiz 7 - Value Stream	*SIMULATION* 5S, Sheet of Fonts	Visual Management	5S	Red Tag	Visual Control Boards	Team Huddle	Gemba Walks
11	Quiz 8 - Flow - Delivery Side	*SIMULATION* 5S House of Cards	6 Big Losses, *CALC* - OEE	TPM & SMED	Andon	Cells & *CALC* - Operator Count	1 Piece	Batch Size
12	Quiz 9 - Flow - Delivery Side	*SIMULATION* Inspection, Letters	Poka-Yoke	Standard Work & 5 Whys	*INDUSTRY* - Aerospace Guest	*INDUSTRY* - Aerospace Guest	*INDUSTRY* - Aerospace Guest	*INDUSTRY* - Aerospace Guest
13	Quiz 10 - Flow - Quality Side	Final tips on Team Projects	Final Tips on Team Presentation	Exam Review	**EXAM 3**	**EXAM 3**	**EXAM 3**	**EXAM 3**
14	*INDUSTRY* - Energy Guest	*INDUSTRY* - Energy Guest	*INDUSTRY* - Energy Guest	*INDUSTRY* - Energy Guest	Course Survey	Course Survey	EXTRA CREDIT QUIZ	EXTRA CREDIT QUIZ
15	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)
16	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Case Study Papers present	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)	*PBL* - Team Projects (subchapters)

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6.0 Implications

6.1 Academia

In the academic arena, the use of professional certifications as external assessments can serve as additional evidence of the consistent quality of the education provided in each subject because it is readily repeatable within the same institution and reproducible at other institutions. Other researchers have witnessed comparable results in educational preparation when course materials were aligned to professional association materials [47].

6.2 Industry

Practically speaking, for industry, professional certifications can clearly illustrate those candidates who possess a well-defined baseline of knowledge, irrespective of the institution they may have attended. This understanding comes from a well-established and agreed upon set of subject standards, commonly referred to as a Body of Knowledge. Again, other research relates the significance of the body of knowledge in systemizing professional practice [48].

6.3 Government

In the domain of government policy, professional certifications can ensure consistent competencies regardless of academic education or industry experience. Furthermore, since the professional associations' body of knowledge has continual input from around the world, the skills have a greater chance of remaining globally relevant. Researchers have seen the positive impact that professional certifications can bring to improving the public wellbeing in academic settings in other advanced economies [49].

7.0 Conclusions

In the current research study, we undertook a records review of an industrial professional association's certification exam on a given body of knowledge, to examine whether student outcomes could be improved based on the results of the previous cycle of students in this external assessment. Overall, our hypothesis was supported, as the results showed that students' rate of passing the external assessment, the SME Lean Knowledge Certificate, was enhanced using the previous cohort results. Each cohort results allowed the researchers to make modifications to the course content via a series of focused case studies using the PDCA cycle.

Positive student outcomes are confirmed. Specifically, the applicable knowledge mandated by our local industry partners regarding the principles, processes, and practices of Lean manufacturing can be readily verified by an external source. All three (3) stakeholder types, student, institution, and industry, now have another reference that can attest that the knowledge of a given student is satisfactory to a well-known, globally consistent standard of excellence.

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8.0 Limitations

8.1 Impact of Demographic Factors

From 2016 to 2021, the course instructor was an adjunct professor, therefore, no demographic information about students was captured. As such, there is no means of analyzing any effects of gender, race, age, et cetera on the professional certification results.

8.2 Impact of Work Experience

While it was not directly analyzed as part of this research study, it appeared that many of the students who passed, particularly on their first attempt, were those with greater work experience. The impact of gaining applicable knowledge about the topic from the working world as compared to or in conjunction with our educational experiences seems to warrant analysis.

9.0 Future Work

9.1 Current Course

Given the disruptions by the Covid-19 pandemic, data from this course and the related professional certification will continue although more descriptive analytics will be performed to determine the movement of mean, median, and minimum values of while also exploring the possible impacts of work experience and demographic factors on the results.

9.2 Other Courses

The authors will conduct similar studies in undergraduate ENGT courses at the study institution. Specifically, the researchers will pilot SME's certified manufacturing technologist in a Spring 2023 course, Machine Elements of Mechanical Design. This mini-capstone course incorporates subject knowledge from the engineering science courses of statics, dynamics, fluid mechanics, and material mechanics. Local SME professional chapter officers have agreed to support the researchers.

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