A Comparison Study of Engineering Standards Taught in Mechanical Engineering Programs in Two Countries

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I was born and raised in Mandi Bahauddin, a small city whose claim to fame is that it is where Alexander The Great famously fought his last major campaign against Raja Porus.

In 2015, I completed my BS in Mechatronics Engineering from the University of Engineering and Technology, Pakistan, where I worked on designing the electrical and mechanical components of a wireless surveillance robot. My team and I developed and prototyped a fully operational UGV that provided multi-terrain surveillance. Our project presentation garnered a great deal of interest from industrial partners at our Open House.

The following year, I secured a fully funded MS position in the graduate Mechanical Engineering program at Shanghai Jiao Tong University in Shanghai, China. As a Research Assistant in the Robotics and Automation Lab under Professor Zhanhua Xiong, I discovered an aptitude for mechanical design. I utilized this newfound talent to build a one-handed, 6-axical robot joystick controller and validated its design through 3-D printing. I presented my novel design at the IEEE/ASME Advanced Intelligent Mechatronics 2018 Conference in Auckland, New Zealand.

While in Shanghai, I also began to play badminton a bit more seriously. Although I had played badminton competitively before in Pakistan, the quality of the opponents I faced in China honed my ability to a level I had never experienced before. A rather debilitating knee injury slowed down my semi-professional career, but I recovered enough to still win a number of championships and local tournaments.

Its difficult to describe one's entire life in a handful of words, but I've given it my best shot. Onwards and upwards has been my personal mantra throughout my academic and professional career. I now hope to continue my previous research in mechanical design while addressing the biggest problems in Engineering Education. My eventual goal is to address the ever-growing need of a better education system in Pakistan.

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Abstract

Mechanical engineering standards are documented codes that enable the design process of machine elements and equipment. These internationally recognized standards are important for reliability, safety, productivity, and efficiency of machines and equipment. International organizations such as ISO (International Organization for Standardization), ASME (American Society of Mechanical Engineers), and several other organizations oversee and constantly update these codes to keep pace with technological advancements in industry, globally.

Literature suggests that one of the major issues impacting mechanical engineering graduates when they begin working in industry is the lack of knowledge and training regarding engineering standards. This results in expenditure of time and resources during initial on-boarding and training procedures for fresh engineering graduates when hired by industry. Although this issue exists in the US, it is more prevalent in Pakistan, where academia and industry are disconnected; , particularly in industries such as oil and gas, fertilizers, cement, and sugar and food industry. Engineering students most often depend on securing an internship to experience industry before graduating, which may not always be possible, yet sufficient.

Scholars identified the lack of knowledge about engineering codes and standards as a major weakness of mechanical engineering graduates. This exploratory study aims to do a comparison of undergraduate mechanical engineering curricula in the United States, and in Pakistan regarding the awareness and implementation of engineering codes and standards

Based on qualitative approaches, online interviews were designed for mechanical engineering graduates to understand graduates' experiences learning common engineering standards in courses and internships. In addition, semi-structured interviews were conducted with CEOs and project managers in industry to provide perceptions of mechanical engineering graduates' knowledge of engineering standards when entering the workforce. This study's findings contribute to the understanding of engineering standards formally taught to undergraduate engineering students, and the conclusion that recent graduates do struggle with learning and implementing the standards when they join the industry. Industry leaders also reaffirm their expectations being not met by recent graduates. Further, by this comparison study, we aim to bring understanding to the broader engineering community of similar gaps in the US mechanical engineering curricula albeit on a smaller scale.

Introduction

Industrial standards are documented codes in engineering that help design machine elements and equipment. They are important for reliability, safety, productivity, and efficiency of the machines and equipment. International organizations such as ISO (International Organization for Standardization), ASME (American Society of Mechanical Engineers), and many others oversee and constantly update these codes to keep up with technological advancements in the industry.

Capitalism is a worldwide phenomenon and the foundational economic system for a majority of countries all over the globe. Capitalism drives industry - and nowhere else is this more visible than in the dramatic globalization of TNCs (Transnational Corporations) and multi-billionaire corporations of today [1]. The engineering industry, as conceptualized by Lasi and colleagues as 'Industry 4.0', has evolved into a giant worldwide setup of organizations that focus on a) mass production capacity, b) fast and automated processes, and c) advertisement and presentation [2].

Academia contributes to industry in two major ways [3]. By providing a suitable venue for research and development, where scientific advancements are fed into technological progress; and creating useful gadgets and devices. High demand for these devices results in the need for increase in production, which is then fulfilled by industry [4]. Conversely, academia also supports industry by supplying trained and skilled professionals who specialize in maximizing efficiency, increasing production, improving designs etc. [5]. According to the authors' opinion and observation, just around 2 generations back, finding engineers to work in industry was difficult, and most of the hands-on work was performed by technicians who received professional training to do specialized tasks repetitively. However, academia is now producing engineers more than ever, with approximately 136,000 in 2018 alone [6]. In order to fulfill the ever-present need for greater production capacities, industry responded by having engineers taking up roles that technicians once used to have. This response helped with providing hands-on training while also serving the needs of the position. However, this approach led to some roadblocks of its own.

One of the major issues impacting mechanical engineering graduates when they begin working in industry is the lack of knowledge and training regarding engineering standards [7]. Although this issue exists in the US, it is more prevalent in Pakistan, where academia and industry are disconnected, particularly in industries such as oil and gas, fertilizers, textile, mechanical manufacturing, cement, sugar, and food industry [8]. Engineering students most often rely on industrial internships to experience industry before graduating. However short term, 1-2 month long internships may not always be sufficient enough to gain the knowledge and experience necessary.

Among the industries mentioned, the 'oil and gas' sector is one of the largest revenue generating industries in Pakistan [9]. Alongside the fertilizer, food, textile, and sugar industries, it makes up a significant portion of Pakistan's Gross Domestic Product or GDP. The pipelines and the machines used in the oil and gas industry are mostly imported, and use the ASME and API standards of operation, maintenance, sizing, and safety. Similarly, the manufacturing

industry mostly implements ISO standards. The textile industry also imports the majority of its machinery, which comes with its own standardized operation and maintenance requirements [8]. With all these multiple codes and standards, it becomes critical for engineering graduates to have knowledge of multiple engineering standards, which is a lacking condition of students upon graduation. As a result, additional training is required for increased proficiency at their jobs, which comes with increased financial and time investment of employers.

Literature Review

Adding sections focused on industrial standards to undergraduate courses is not an entirely new concept in engineering education. Leachman & Pezeshki [10] explored a capstone mechanical engineering design course while also teaching the standards used and implemented by associated industrial sponsors. Surveying both undergraduate students and industry sponsors revealed that a shift of the curriculum toward a broader understanding of engineering standards implementation helps save time spent in the design process. Since the codes for design specifications are already documented and established; the authors recommend the incorporation of industry standards into undergraduate education.

Another interesting strategy to engage undergraduate mechanical engineering students in standards education was implemented by Phillips & McPherson [11]. The researchers took everyday household items such as toaster, grill, and ladder to class and asked students to find out standards are incorporated to design and manufacture them, as well as look for relevant literature on standards. This practice increased student engagement in standards learning and a follow-up survey indicated that students felt more confident to use standards in their own design projects.

Being knowledgeable of engineering standards has been found to significantly enhance the credibility of literature utilized by mechanical engineering students in their course reports and projects [12]. In the experimental study, a group of randomly selected students were provided with an hour-long library-led instruction about the effective use of scholarly articles and engineering standards. The selected group of students performed significantly better and cited more sources compared to their peers without the information. The article notes that the implementation of appropriate engineering standards has been specified by the American Board for Engineering and Technology (ABET) as a key criterion for curriculum assessment. However, additional research is needed to increase the diversity and quantity of engineering standards used and reflected in student reports.

In order to make engineering standards knowledge more accessible, Phillips et al. [13] proposed a free online program on standardization for product development that offers knowledge ‘beyond the textbook’ and prepares students for full-time careers in industry. The multi-module program encompasses the overview, in depth anatomy, search techniques, and everyday utilization of standards. The program was implemented with flipped classroom and team-based project instruction in mechanical design engineering classes with great success.

Not only the knowledge of engineering standards is necessary, but educating students on the real-world applications of engineering standards is crucial. Currently, standards education is lacking and not fully incorporated into the undergraduate mechanical engineering

curriculum. So far researchers only mentioned Purdue University in the US as an example of successful integration of codes and standards education into the mechanical engineering curriculum [14]. A potential method to encourage the use of standards by students is requiring them to build academic products and projects by properly following engineering standards, and then sharing the product with potential employers to show their proficiency at industrial standards. Additionally, industry should be invited to participate in raising awareness of standards in academia through information sessions, company tours, informative videos, and guest speakers.

In a similar study about teaching quality control to students through industry partnerships, McPherson & Reiter [15] mentioned that Purdue University is partnering with industry to bring active learning projects to a course named 'Quality for Manufacturing'. This approach involves directly importing product designs and parts from industry, letting students perform standardized quality assessment procedures on them, and finally reporting back to industry advisors for feedback. This practice helped students gain transferable skills and knowledge of industrial standards for future professional careers.

The importance of standards in engineering education was also highlighted by Khan and Karim [16] where they mentioned several organizations that develop and implement codes and standards including ASME (American Society of Mechanical Engineers), ASTM (American Society for Testing and Materials), IEEE (Institute of Electrical and Electronics Engineers), and ANSI (American National Standards Institute). Such codes are noted to be critical in application of design, development, and testing for students' projects. The authors concluded with recommended benchmark standards for entry-level engineers.

Gbur & Solomon [17] also reported the importance of standards and arranged a university workshop to raise awareness about the issue. Guest speakers from six standardizing organizations were invited, who presented and engaged in discussions with both students and faculty regarding industrial standards. The authors suggest that implementing such practices is essential for communicating the required knowledge of industrial standards to universities and providing their graduates with the necessary skills.

The importance of engineering standards education is not only apparent in mechanical engineering studies, but also in multidisciplinary fields. In their chapter on sustainable development through standardization, Idowu et al. [18] addressed the need for multidisciplinary education about standards. They emphasized that many national companies adopt standards on the basis of the language of workers, accessibility, and other factors, and might not follow global standards. Therefore, there is a need for inclusivity in standards which will come from multidisciplinary knowledge of various standards followed across the globe.

Theoretical Framework

Competence as defined by Glaesser [19] is the disposition that allows a person to successfully meet and cope with situational demands. In terms of this study, competence can be defined as the skills required for engineering graduates to fully thrive in the workplace, particularly with regards to their knowledge and familiarity with industrial standards and codes. To cultivate this competence, the field of engineering education must first be aware of the

current situation of engineering graduates' preparedness and knowledge of industrial standards upon graduation. As such, competence is necessary in mechanical engineering undergraduate programs, which is the focus of this study.

Research Questions

This study aims to shed light on the issue of engineering graduates' knowledge and familiarity with industrial standards in a cross-national comparison between the United States and Pakistan. The perspectives of engineering graduates as well as industry leaders will be utilized in understanding the current situation in both countries in terms of engineering graduate preparedness for industry jobs. As such, the research questions of this study is:

RQ1: How do recent mechanical engineering graduates describe their preparedness for industry needs around standards? What courses or projects do they identify as particularly relevant to developing that knowledge?

RQ2: What are the perceptions of industry leaders about recent graduates' preparedness to join industry regarding their knowledge and competency of engineering standards?

The first research question illuminates the entry-level professional engineering experiences in industry, and links them to the earlier perceptions of students about use of standards in industry. The second research question attempts to address the same scenario, but with employers' perspective. Both the questions focus on standards currently implemented in industry.

Methods

Study Methodology

The method used for this project was a case study, which is a useful approach for detailed observations regarding developments among individuals, organizations, or situations [20]. Occasionally, case studies are chronological, that is, they are carried out over time; in most cases however, case studies are direct studies that are only carried out in a particular instant of time. In the present study, our case study has multiple data sources to authenticate our hypothesis by looking at it from more than one perspective.

A case study is also a relevant approach since this study seeks to investigate a phenomenon that has not been widely discussed in academia yet extensively employed in industry. It has been observed that recent engineering graduates face challenges associated with this phenomenon, and thus, the interview data determines the importance of this phenomenon. The aim of this study is to establish the need for including industrial standards as a part of engineering curricula to facilitate the transition into industry.

Sample

The sample in this study consisted of both mechanical engineers as well as industry leaders in both the United States as well as Pakistan. Participants included 7 engineers who

were between the ages of 25-30 years old and identified as male. One industry leader from Pakistan and one from the US, whose ages were approximately 50 years old, were also participants.

Participants were recruited through snowball sampling as well as through recruitment emails and advertisements. The term "snowball sampling" here indicates that a recruitment technique was used in which participants were asked to help identify additional (potential) participants for the study. In total, six participants were recruited from Pakistan and three from the United States.

Inclusion and Exclusion criteria

The following inclusion and exclusion criteria were followed to determine participant eligibility for the study:

Engineers. Engineers were required to have graduated within the past five years from their university in Pakistan or the United States. They also were required to be working full-time in any role or area but within an industrial job.

Industry Leaders. Industry leaders were required to have had industrial experience for a minimum of 10 years and to have been at their current leadership/management position or role for at least 2-3 years.

Instrument/Protocol

Semi-structured interviews were designed for students with open-ended questions directed towards perceptions regarding industrial standards used in industry for Pakistan and the United States. Some basic demographic information was collected as well as information about engineering degree programs to warm up the participants for further discussion. Next, the participants were encouraged to expand on their learning experiences in academia as well as in industry in terms of standards. To maintain coherence and focus during the interview, some guiding questions were also included.

The interview protocol for industry leaders was semi-structured as well. They were prompted to share their thoughts and perceptions about the preparedness of entry level engineers who join the workforce. A question was introduced to start the conversation, with follow-up questions encouraging the participants to expand on their perceptions and provide insights regarding the importance of industrial standards and why they should be taught in academia.

Analytical Method

After the collection of data from focus groups and interviews, thematic coding was used to analyze the data. Recordings were transcribed and coded line by line first, and paragraph by paragraph second. Relevant codes and subcodes assigned to lines and paragraphs were then reduced in number and similar codes were merged in an attempt to reduce the overall number of codes. Codes that repeated in transcripts from a single participant or multiple participants were considered important enough to give rise to thematic information, which means that the lines and paragraphs in transcripts that were relevant to those codes were noted as emergent.

Such emergent themes were extracted from each paragraph and overall themes emerging from data were recorded until a saturation point was reached. “Saturation point” refers to the point at which codes could not be reduced anymore, and associated themes. The final themes were then used to derive conclusions that provided full or partial answers to the research questions of the study.

Findings

Initial findings indicate that there is variability in how industrial standards are taught in mechanical engineering programs in Pakistani universities versus the US universities. Recent engineering graduates and industry leaders in both countries shared their perspectives on the importance of standards and student preparedness to join the workforce. The dominant themes that emerged from the semi-structured interviews are stipulated below.

Graduates from Pakistan

The interviewees worked in industrial sectors of oil and gas, sugar processing, mechanical hardware design, analysis, and manufacturing. When prompted about the teaching of industrial standards, the most emergent theme in the participants’ answers was their consensus on the aspect that in mechanical engineering courses, the focus is on teaching theoretical perspectives rather than practical applications. Theory-heavy courses such as engineering dynamics, fluid mechanics, and mechanics of materials are taught where students learn how to solve problems relating to Taylor series, Bernoulli’s equation, and pressure moments. Such courses are usually 3-credit courses and take up most of the required credits for graduation. However, only single credits are assigned to the lab work, practicals, and course projects for the same courses. Therefore, students prioritize these theory-based classes compared to classes with less credit hours. Little to no importance is given to the already established codes used in industry when it comes to course projects and final year projects.

Focus on theory severely limits the preparedness of engineering students to join the workforce after graduation. According to one participant, only 10 percent of the knowledge gained from university was utilized in industry in terms of standards, and 1.5 to 2 years of additional training were spent to learn the practical implementations of standardized codes. Three of the participants mentioned the use of ASME, ANSI, API, ISO 9001, and ISO 14001 standardized codes in design and maintenance of gas turbines, oil pumps, oil and gas pipelines, welding, forming, rolling, galvanization, general manufacturing, and use of safety equipment on worksites.

The importance of standards was acknowledged by all the participants. In their recommendations towards a better engineering curriculum, two participants proposed the addition of a few chapters and dedicated lectures in every course, in which the instructors teach about industrial standards relevant to the respective course. One participant suggested that the final year project (mandatory for all students) should be made less research-based and more industry-oriented, and the stages of design, analysis, and fabrication of the project should all follow the relevant standards.

Graduates from the US

The interviewed participant worked first in a consulting company, then in a company that designs residential and office buildings, convention centers, and commercial spaces in the DC area, and later in a data center. When asked about the knowledge of industrial standards prior to graduation, he noted that the courses taken during their freshman to junior years such as engineering ethics and energy efficiency electives provided knowledge about factors of safety, tolerances, and other standards expected with the design aspects of machine elements. In their senior year, the participant mentioned that their design project conducted with the Baja team allowed him to design, analyze, and fabricate a complex integral part of the automotive suspension system known as 'the upright.' In this project, the participant was required to follow industrial standards for dimension tolerances followed by stress analyses for a required factor of safety.

While working as a mechanical design engineer and architect in the industrial sector, the participant described their experience with a variety of standard mechanical codes, construction practices, and design guidelines including ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers), IMC (International Mechanical Standards), IBC (International Building Standards), and energy efficiency benchmarks. Although detailed knowledge about where to look for the specific codes was not taught during undergraduate courses, the participants were significantly aware of the existence of proper codes and applied them in their full-time engineering roles.

Another participant included a recommendation for the mechanical engineering curriculum, which was the proposal of additional electives focused on industry specific topics. They mentioned that this will help interested students gain knowledge of industrial standards implemented in respective domains. Overall, the participants got information about industrial standards during their undergraduate degree through elective courses and projects and emphasized on the importance for their preparedness to join the workforce.

Industry Leader from Pakistan

The participant co-founded his company in 2003 and started manufacturing automated heavy mechanical equipment such as road blockers, boom barriers, bollards, turnstiles, and fire doors in 2009. He emphasized the importance of standards for reliability and efficiency of the mechanical products, and their compatibility with other systems. In his experience, export quality of industrial products is achieved by following international engineering standards, which greatly increases the market value of such products. Apart from mentioning UL (Underwriters Laboratories) standards and other manufacturing standards for mechanical equipment, electronics and fire doors, the participant also considered the workplace safety standards critical for the physical well - being of on-site workers.

The participant is convinced that universities in Pakistan are producing engineering scholars, and not practical engineers. While he recognized the value of creativity and talent of fresh undergraduate engineers, he also believed in learning and applying engineering standards knowledge. In terms of suggestions, the participant proposed that industrial standards should be

taught from the third year of undergraduate programs. In addition, he mentioned that India's engineering education system offers a practice focused track for interested engineers, which, while longer than a traditional undergraduate degree, enables students to apply for leadership roles upon graduation. Lastly, the participant recommended that regular workshops and exchanges between industries and universities should be conducted to ensure that both instructors and students are updated on current industry operations and engineering standards.

Industry Leader from the US

The participant graduated from the US university in 1983 with a bachelor's degree in mechanical engineering and has been working in different industries ever since. His current leadership role is a senior manager in the field of robotics. Talking about his experiences with recent graduates joining the workforce, he noted that they lack the knowledge of industrial standards, specifically regarding dimensioning, tolerance, testing, vibration/thermal analyses, drawing, manufacturing, and even documenting. The participant added that the lack of knowledge results in longer times spent in any phase of the design process which impacts company efficiency and productivity negatively. To address this issue, the participant's company implemented a six-month training program for recently graduated engineers.

In terms of the mechanical engineering curriculum, the participant recommended structured capstone projects that ensure every group member becomes proficient in all phases of the design process. For example, the participant noted that for hardware design projects, every student in a group must be involved in preliminary material search and documentation, creation of CAD drawings, alternative design production, and selection of the most cost-effective fabrication method for hardware components. The participant stated that usually in group projects, students gain experience and therefore master one aspect of the project (for example, simulation analysis). According to the participant, once the student joins industry they are confronted with mastering all aspects of the design process which include learning standardized processes from scratch. In order to facilitate the transition into industry, the participant suggested that technical universities in the US need to provide thorough training of industrial standards and their application.

Discussion

This study provides valuable perspectives towards answering the research questions. Recent graduates in Pakistan identified that there was little to no training in industrial standards in mechanical engineering courses and explained their learning experiences after joining the workforce. This made them less prepared to adjust to the requirements of industry. On the other hand, recent graduates in the US acknowledged the importance of standards and noted that they were taught about codes and engineering best practices in engineering ethics and some elective classes. However, after joining the industry they still spent some time learning and implementing the standards specific to that industry.

The industry leaders' perception of recent graduates' preparedness to join the workforce asserted the importance of teaching standards. They also had useful suggestions for bridging the gap between academia and industry. Thus, a collaborative effort is necessary to ensure that

the requirements of industry are addressed in the university curriculum, especially regarding standards.

Qualitative Quality

A set of parameters [21] were used to determine the research quality in this study. First, the topic of study is about engineering standards used in industry, which is relevant in current time, as the issue of current engineering graduates' preparedness still persists. Second, appropriate theoretical constructs (competency in educational theory), sampling with respect to time and context, data collection, and data analysis procedures are proposed that characterize rich rigor in research. Third, investigating the importance of a significant issue (i.e., knowledge of standards) and incorporating the findings into academic plans urges a significant contribution to the field of engineering education. Fourth, methods used in the study (focus groups and interviews) are connected with research questions and literature identified earlier, providing detailed insights from participants. This fulfills the goals of the study about contemplating the importance of engineering standards, and thus reflects 'meaningful coherence' in the study.

Positionality Statement

There is a possibility of the impact of researcher bias on the interview questions, as the researcher believes that there is a lack of emphasis on engineering standards in the mechanical engineering curriculum. This belief is based on the researcher's experiences during their undergraduate degree and professional career. When the researcher started working in industry as a mechanical design engineer, he struggled with the applications of design standards, tolerancing and documentation. The researcher had to work overtime to fulfill his responsibilities regarding their position.

The researcher also is from Pakistani origin and identifies as a male. The Pakistani participants might have felt more comfortable with the researcher due to similar backgrounds and provided more in-depth answers.

Limitations and Future Directions

As is often the case with qualitative research, the number of participants in this study is limited. The criteria for sampling are also strict and they limit the participants to one institution in Pakistan and one in the US. In that sense, the results from this study might not generalize to all engineering institutions in Pakistan and in the US. This study is limited to mechanical engineering programs only, and considers the industrial standards used by mechanical-oriented industries. Additionally, there were no female participants in this research, which severely limits the perspectives included in this study. However, the possibility to consider other engineering fields and to include participants from other genders may be explored in our future research. For future research, the findings could be utilized to develop curriculum interventions, and measure its effectiveness.

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Appendix

Interview Protocol for Engineering Graduates

Following are some of the questions for the engineering graduates regarding their education and their experiences:

1. During the course of your undergraduate degree, did you learn about the standards followed in the industry? If yes, in which course and to what extent? Did you learn the practical implementation of those standards? (Basic yes/no question as a precursor to the follow-up qualitative questions)
2. What is your perception regarding the importance of teaching engineering standards during the four-year undergraduate coursework?
3. How did you standardize the design of machine elements in your course projects? How did you standardize the piping and instrumentation diagrams (P&IDs) in the course projects?
4. How would you explain your preparedness to join the oil and gas sector after graduation, regarding the standards used in that industry?
5. Did you work as an intern in the oil and gas industry while you were still a student? What new things did you learn by working in close proximity to full-time engineers in terms of using industrial standards?
6. How did you cope with the requirements of the industry after joining?
7. Considering the experience that you got by working in the industry until now, do you feel that you needed to learn more about engineering standards during your undergraduate degree? (Guide question to channel the conversation back towards topic if needed)

Interview Protocol for Industry Leaders

Following is a list of some of the questions asked from industry leaders:

1. Do you feel that most fresh graduates lack the necessary knowledge of standards used in the manufacturing industry? (Basic yes/no question as a precursor to the follow-up qualitative questions)
2. What are your thoughts regarding the importance of industrial standards, and why should they be taught in the university?
3. What is your perception about the preparedness of recent graduates to join the workforce?
4. What are the general areas in which the new hires require additional training and resources after joining the industry?
5. What would be your suggestions and recommendations to improve the engineering education curriculum to ease the academia-industry transition for fresh graduates in terms of engineering standards?