The Gap Between Engineering Schools and Industry:A Strategic Initiative

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***Abstract*—The long-standing gap between engineering education and the industry (the Gap) has been acknowledged in literature extensively. In this paper, the Gap has been addressed philosophically from three different aspects: the demarcation between science and engineering, the causes of the Gap, and the strategy for bridging the Gap. The targeted education level in this paper is the bachelor level. The Gap is caused by the absence of feedback from the industry to engineering schools. This paper contributes to the philosophy of engineering education by proposing a strategic initiative to bridge the Gap. The expected outcomes of the proposed initiative are the following: Re-classification of the majors available in engineering schools and redesigning the knowledge taught in these schools to match industry needs. These outcomes could be achieved by firstly giving engineers the opportunity to write about their own experience at an industry level in engineering journals and, through their writing, schools get an idea of what is going on in the industry. Secondly, accrediting agencies such as ABET should grant a higher rank to engineering schools based on what they have done over time to bridge the Gap. Lastly, PhD research could be utilized to improve the undergraduate curriculum. A PhD student could work for a company, then return to school two years later to present their findings and observations.**

Keywords*— Undergraduate, Engineering curriculum, Engineering profession, Industry involvement, Industry sponsorship, Cooperative education, Philosophy of engineering education, Gap Engineering.

I. INTRODUCTION

The purpose of the engineering profession, as Count Rumford put it in 1799, is "*the application of science to the common purposes of life* [1]." Hence, engineering is not a science. Ideally, scientists conceive knowledge while engineers use this proven knowledge to make life better. In practice, there is an overlap and grey areas between scientists and engineers. This occasional overlap between the engineering and science professions is a natural occurrence but it does not mean they can be lumped together into one thing. However, the textbooks adopted by engineering schools are science-based. Therefore, the difference between science and engineering from the perspective of engineering students becomes vague [2], as the committee of Commission on Engineering and Technical Systems National Research Council explains it as follows:

"… *The emphasis on theory and analysis at the expense of a practical orientation toward synthesis and design is now generally seen as having gone too far in certain areas. Students may in many cases be acquiring the notion that analysis itself - rather than the solution of engineering problems - is the focus of engineering work. Rigorous grounding in fundamental engineering science is essential, as these are indeed the building blocks of engineering; but the existing curriculum tends not to impart an integrated picture of engineering, nor does it give a sense of the relationship of analysis to the design and synthesis of complex engineering systems. From the standpoint of industry needs, these are serious shortcomings…*"

Engineering education does not only share the same knowledge of science, but it has evolved differently to other professions. The teaching of other professions, such as law or medicine, has evolved from apprenticeships and purely practical and technical disciplines to an academic discipline. On the contrary, engineering education was established in colleges by scientists rather than by practitioners [1].

Both the science-based nature of engineering education and its unique evolutionary path (compared to the education of other professions) create a huge gap between the industry and engineering colleges. In this paper, for the sake of simplicity, the gap between engineering education and the needs of the industry is denoted as the "Gap", with a capital letter G. The symptoms of the "Gap" are obvious, because once engineers graduate, they need at least 2 to 3 years of practice to master the engineering profession. The value of the engineers in the industry increases with the number of years they have been practicing engineering. Of course, if the engineer holds a graduate degree, their value to employers increases too. Yet, the value of experience outweighs the value of the graduate degree.

To bridge the "Gap", employers dedicate many of their resources to train recently graduated engineers to become acquainted with industry standards and practices (that are not taught in engineering schools) and the recent advances in the industry (that have not been included in undergraduate textbooks). The "Gap" is no longer debatable. It has been acknowledged by many researchers [3- 5]. One can infer from the responses of graduate engineers in [3] that engineering colleges do not need to improve their way of delivering the information to the students, but they need to enhance the raw knowledge taught at engineering schools. Also, the authors in [4] conducted a survey to gauge employers' satisfaction about the competency of recent graduate engineers. Among the technical skills, the employers were mostly dissatisfied with the graduates' ability to design and conduct experiments. A study in [5] is conducted to find the engineering students' perspective on

978-1-5386-1174-6/18/$31.00 ©2018 IEEE

what they have learned in engineering schools. The top three competencies that the engineering students believe they have learned are: willingness to learn, understanding the fundamentals of science and engineering, and understanding the role of mathematics in the world. It is clear from the responses that practical perspective is lacking in the engineering students' mind. So, the data collected lead the author in [5] to the following conclusion: *There is evidence from the data that students' learning is based solely on the academic viewpoint*.

	#1	#2	#3	#4
Engineering	Picks Up where Scientist left off	Uses Science to achieve a practical end	Its core is Making	Results in material wealth
Science	Stops Where Engineering starts	Uses Technology to conceive knowledge	Its core is discovery	Results in an academic achievement

Fig. 1. differences between science and engineering

Reforming engineering education is attempted in [6]; this reform is called Conceive-Design-Implement-Operate (CDIO). The main goals of CDIO are to are to: (i) provide engineers with a deeper knowledge of technical fundamentals, (ii) to train engineers to create and operate new products or processes, and (iii) to improve engineers' understanding of the importance and strategic impact of research and technological developments on society. Also, the authors in [7] proposed an educational program called Lean Engineering Education (LEE) in order to reform engineering education. Although both CDIO and LEE would greatly contribute to the evolution of engineering education, they let (i) the teaching faculty be solely in charge of determining the curriculum to meet industry needs and (ii) they focus mainly on improving the way of delivering knowledge to the students rather than improving raw knowledge itself. Unfortunately, the faculties are part of the problem [3,2] because their expertise is focused more on research-oriented knowledge while the engineering students lack practical-oriented knowledge. Also, the curriculum itself is diagnosed as the cause of the "Gap", and not how the information is delivered to the students [3]. Briefly, both CDIO and LEE lack the criteria to monitor the alignment of the educational progress with the needs of the industry.

In this paper, the issue of the "Gap" has been addressed and a strategic plan is proposed to redirect the evolutionary path of engineering education towards industry needs. A successful reform of engineering education means we must understand *where we are right now*, the *destination we are seeking*, and *how to get there*. In order to know *where we are right now* (a diagnosis of the current situation), the interaction between the industry, research advancement, and engineering colleges are presented. Engineering education is found to have been evolving solely based on research advancement while industry needs are being ignored. Therefore, it has been suggested to include feedback from the industry to engineering colleges in order to get from *where we are now* to *where we want to be*. One may ask: where do *we want to go*? In order to answer this question, we have to know what engineering is and what the boundaries between engineering and science are. Once we understand the term "engineering", the vision of the proposed plan can be seen clearly. Therefore, the boundary between engineering and science in this paper is discussed. Then, the expected outcome of this strategic plan would tell us exactly *where we want to go*. We *want to get to the stage* where the raw knowledge taught in engineering schools is designed to match industry needs. Since the raw knowledge is going be redesigned, the engineering departments have to be redesigned according to industry needs. The aforementioned goals or outcomes are discussed in this paper in detail.

The following section addresses the boundary between science and engineering so that the vision becomes clear to the reader. Then, in section III the causes of the "Gap" are presented. After that, the proposed strategic initiative is presented in section IV. Lastly, our conclusion is presented in the last section followed by a list of references.

II. Demarcation between Science and Engineering

The term "demarcation" is coined by the philosopher Karl Popper to erect a boundary between science and pseudoscience [8]. This means the "separation between" or the distinct line separating science from pseudoscience. The term "demarcation" is used in this paper to find the distinct line that separates science from engineering. The introduction mentions that engineering students do not realize the difference between science and engineering until they start practicing their profession [2]. If engineering students received the same education as scientists, they would practice engineering like a scientist would, which widens the "Gap". Therefore, to lessen the "Gap", the identity of engineering in schools must be distinguished from science at educational institutions.

In an effort to learn the difference between science and engineering, this section is dedicated to laying out a philosophical background to contrast the identity of engineering. This is a necessary step to reform engineering education.

There is a great interdependence between science and engineering. Science always looks for recent advanced technology developed by engineers to perform their experimental work, while engineers always look for proved scientific theories to make technological advancement [9]. Also, the different logical reasoning between science and engineering is very subtle [9]. The interdependence and shared reasoning between science and engineering makes demarcation between them a cumbersome task if we want to build a definition which considers all the details. Therefore, since our purpose in this paper is to reform education, we will try to provide enough of a demarcation merely to serve our purpose without involving specifics.

Many attempts have been made to define Engineering. One such attempt has been made by Luegenbiehl, [10] "*the transformation of the natural world, using scientific principles and mathematics, in order to achieve some desired practical*

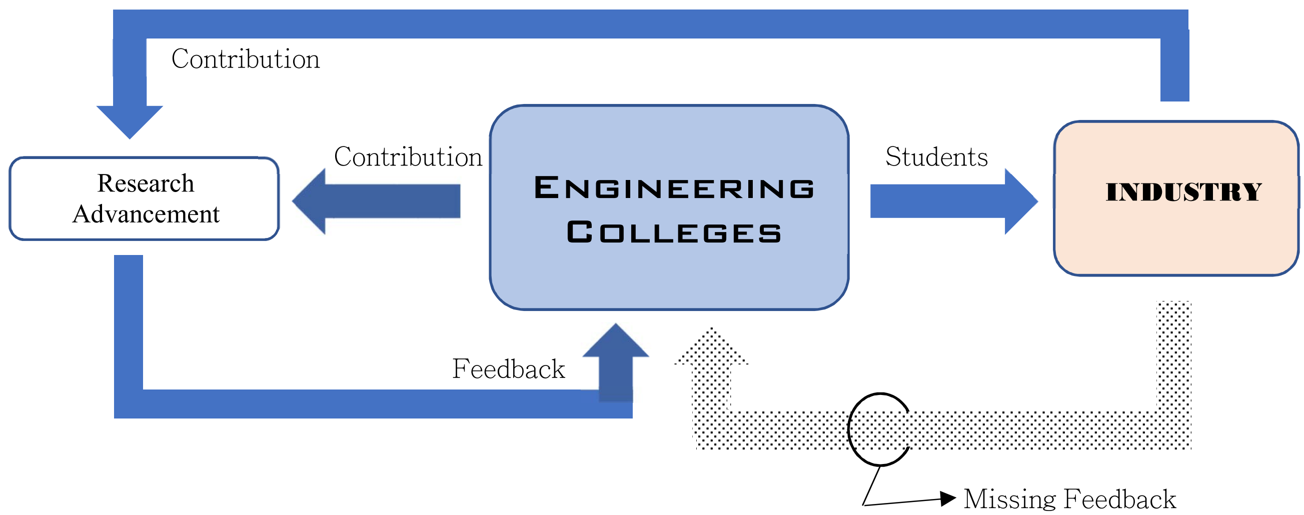

Fig. 2. intercommunication between Industry, Engineering Colleges, and Research

end." Another definition by Lee Shulman [11] states "*An engineer is someone who uses math and the sciences to mess with the world – by designing and making things that people will buy and use; and once you mess with the world, you are responsible for the mess you've made.*" Both definitions agree that engineering is about doing something useful using science. Therefore, the engineer usually picks up where the scientist has left off.

In addition, Bo-Cong lists few differences between science and engineering [12]. He noticed that the core of science is discovery while the core of engineering is making. Also, he observed that scientific activity results in academic achievements or new scientific knowledge, while engineering results in material wealth. Fig.1 summarizes the above discussion.

Considering the above discussion, there is a consensus that engineering isn't science. Consequently, engineers should receive a different education from scientists. Also, engineers are not only required to know recent proven scientific theories, but they must know how to implement them in the real world too.

III. Cause of the Gap

At the very outset of engineering education, schools derived their textbooks from science textbooks. This norm has continued since then with modifications and reforms being made to engineering textbooks in light of scientific advancements alone. The link between engineering colleges and the industry has remained a one-way relationship. Colleges are solely in charge of editing textbooks in isolation of the industry. It turns out that the industry is left with no option other than to bridge the "Gap" unilaterally. Therefore, the industry chooses to hire graduates with high GPA so that they can learn fast in order to minimize their training time.

The interrelationship between engineering colleges, the industry, and research advancement has paved the way for the evolution of engineering education. Both the industry and academia are contributing to research advancement. Then, based on the advancement attained in research, engineering colleges edit the curriculum accordingly. In other words, there is feedback from research to the engineering colleges. Consequently, engineering education has been evolving towards a scientific-research-based education.

Although, engineering colleges are exporting students to the industry, editing and improving the curriculum does not consider industry needs (see fig. 2). In other words, the feedback link from the industry to schools is missing. This may explain why postgraduate students tend to be more acquainted with research rather than with practical-oriented knowledge. This is because Bachelor-engineering students receive more training to start a research career rather than to practice engineering in the field.

From the above discussion, it can be concluded that the absence of industry feedback to improve engineering education is the cause of the "Gap". However, retaining the missing feedback link requires great effort which, once established, would start a long journey of reform and modification to engineering education. This journey may take decades. The next section proposes a strategy, or a plan, to establish the missing feedback link and to devise an efficient process in order to minimize the period of reform.

IV. Proposed Strategy

Although many researchers demand a change to engineering education [6, 13], they expect the engineering faculty to perform this change. Unfortunately, the faculties are part of the problem because their background is researched-based [3] and more research is not what the industry needs. The industry needs graduate students with more practical-oriented knowledge. On top of this, the faculties themselves are the byproduct of the dysfunctional educational process. So, if change came from the faculty end, it would input more science-based material into the curriculum, which is not the desired solution either. Another suggestion is made in [13] that would incorporate the participation of the industry into the educational process. However, this solution is completely dependent on the

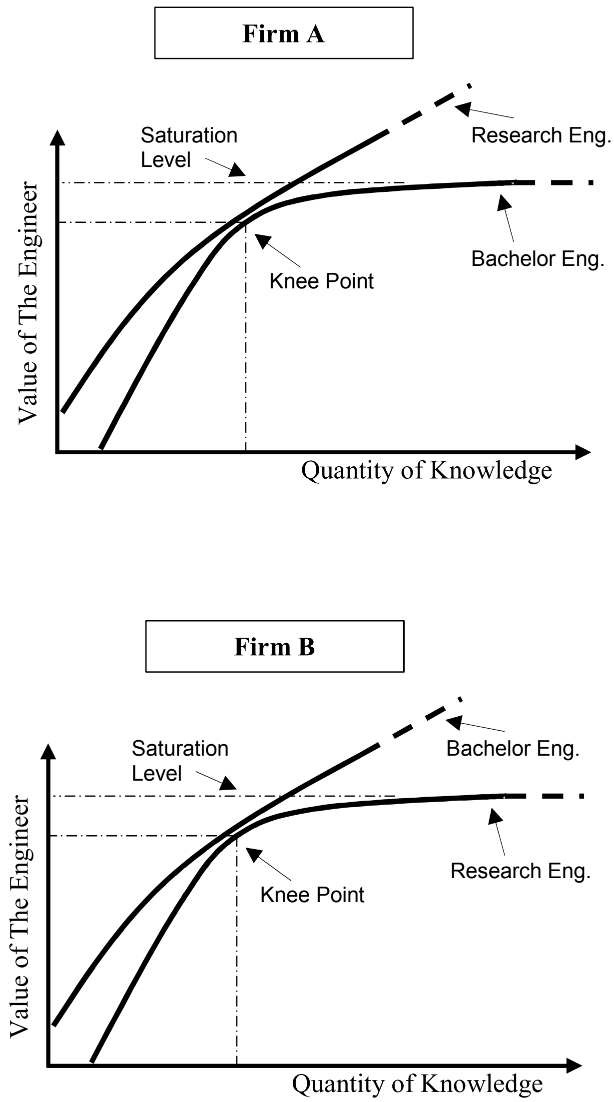

Fig. 3. Explanatiry Curves of Firm A and Firm B to shows the correlation between the value of the engineer and the knowledge.

industry's enthusiasm to participate. In addition, the industry always chooses the cheapest option to maximize their profits, which is to train newly hired engineers rather than get involved in reforming the educational process.

Any change or reform to the curriculum MUST involve the industry and, of course, the faculty must be open to collaboration and reform. The question here is how do we bring engineering knowledge from the industry into schools? The answer to this question is explained in the following two subsections. The first subsection explains what the industry needs by demonstrating the interrelationship between the knowledge of the engineer and the value of an engineer. Once the industry needs are understood, we can set goals for the proposed plan. The second subsection explains how to acquire feedback from the industry to engineering colleges. Once the feedback link is established, the evolutionary path to engineering education will be redirected towards industry needs.

A. Expected Outcomes (or Goals)

A career path determines the type of skills and knowledge that should be acquired by the student. For instance, research skills and modeling etc. would be more in demand by research centers than by small firms selling maintenance services. Engineering education has to consider the career paths available in the market and redesign their curriculum accordingly. This can be done by finding the knowledge needed by the industry, then incorporating it into the curriculum. The following example helps to explain the aforementioned idea.

Let us imagine two engineering firms with two different business activities: Firm A and Firm B. The former (Firm A), is a research & development lab affiliated with an intercontinental company. The latter (Firm B), is a moderate-sized consultant engineering office. Both firms want to hire two newly graduate engineers. The first engineer holds a bachelor's degree and the second engineer holds a postgraduate degree (PhD or master's degree). For the sake of simplicity, the Bachelor Engineer (BE) refers to the engineer who holds a bachelor's degree while the Research Engineer (RE) refers to the engineer who holds a postgraduate degree.

Both firms are depicted in fig.3 where the horizontal axis shows the quantity of knowledge that an engineer has, and the vertical axis shows the value of the engineer to the firm. For firm A, notice the value of BE engineer increases with the knowledge he has. However, his value reaches a certain limit (the knee point in fig.3) where the quantity of knowledge he has does not significantly affect his value to the industry. On the contrary, the value of RE keeps increasing as his knowledge increases. This is because Firm A needs engineers who can perform research, modeling, and data analysis. The opposite can be seen in Firm B. BE's value keeps increasing as his knowledge increases while RE engineer reaches a knee point eventually for Firm B. This is because Firm B requires an engineer who is good at troubleshooting technical problems, knows the company's standards and technical legislation, and can lead a team project.

It can be concluded from the above discussion that there is a strong connection between knowledge and career. This leads us to the first goal which is to **find the knee point of each specific branch of engineering knowledge and redesign the curriculum accordingly**. This goal cannot be attained without understanding industry needs, and the industry needs cannot be understood unless a feedback link is established from the industry to academia.

Another manifestation of the "Gap" is the difference between engineering specializations in the industry compared with the ones in universities. Engineering specializations in schools are classified based on a scientific view. For instance, the specializations in schools are classified as Electrical Engineering, Petroleum Engineering, Mechanical Engineering, etc. However, the industry is not bound by the school classification system most of the time. The industry classifies the engineering professions from a practical standpoint. For instance, the industry engineering specializations are Maintenance Engineering, Project Engineering, Construction Engineering, Planning Engineering, Procurement Engineering, Design Engineering, etc. Therefore, the second goal of this initiative is to **reconfigure the specializations in engineering**

colleges to follow the specializations as they are the in industry, not the other way around. Otherwise, the industry would spend years training newly graduated engineers. Again, this goal cannot by attained without having feedback from the industry to academia readily available.

It seems there is a long journey ahead of us to study industry needs, in order to reroute the engineering curriculum to match them.

B. What can be done?

Basically, when a competitive environment is created among educational institutions, they will compete to keep up with the challenges imposed on them. Students who have graduated from an engineering college that embraces the right approach to reform will be favored by employers. Similarly, graduate students coming from an engineering college which has not implemented change are less likely to get hired. Employers favor some engineering schools over others based on their own accumulated experience of recent graduate engineers from different colleges. This would build up engineering colleges' reputations. Consequently, the chances of receiving donations, winning research funds, or receiving applications from students with an excellent academic history will be dependent on that school's reputation. A bad reputation means lower chances of survival in the education business. This approach is similar to the evolutionary process. So, the essence of the proposed strategy is to create that competitive environment.

So, what can be done? Simply, the missing feedback link shown in fig.2 needs to be established. Once feedback is established, the task of monitoring the alignment of education with the industry becomes doable. Feedback from the industry to engineering schools could be established by using accrediting agencies, PhD research, and engineering journals (all of which will be explained later). Other sources of feedback could also be included such as the Cooperative Engineering Education. Then, in order to create a competitive environment among engineering schools, regulatory authorities could implement policies to create such an environment.

The accrediting agencies, such as the Accreditation Board for Engineering and Technology (ABET), would be a great incentive to establish feedback and to create a competitive environment. Typically, the accrediting agencies renew the schools' accreditations periodically. If a school has reached the standards set by the accrediting agency, the school will be granted a tier status based on its performance. The tier status of schools creates a competitive environment in the education business so that they strive to achieve excellence. The accrediting agencies could also introduce two new evaluation criteria; one related to establishing a feedback link and another related to the "Gap". The accrediting agencies would use the first criterion to periodically monitor the college's progress in establishing a feedback link from the industry to colleges. The other criterion would be used to measure how much the college has done to bridge the "Gap", using valuable information collected from the feedback link. This way, the accrediting agencies could divert the evolutionary path of engineering education from being scientific-oriented in nature towards a practical-oriented education.

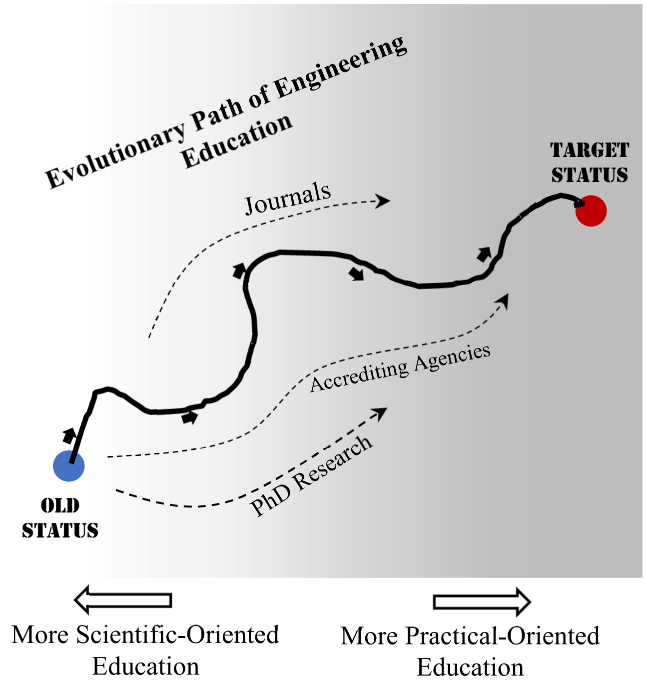

Fig. 4. PhD research, Engineering Journals, and Accrediting Agencies all can deter the evolutionary path of engineering education from being scientific-orinted (Old Status) to being more Practical-Oriented education (Traget Status).

Engineering journals can contribute to the evolutionary process of engineering education too. It has been a long-standing tradition that the papers submitted to engineering journals are edited by engineers from academia. These papers are going to be rejected or accepted according to the norms developed by engineers in academia. This means that the journals are not useful sources for obtaining any feedback from the industry. So, it is suggested to open the door to engineers in the industry to let them write about their problems and the situations they experience in their profession. Articles submitted by engineers in the industry should not be subjected to the acceptance and rejection standards of those papers submitted by researchers in academia. New norms of acceptance and rejection have to be developed which are suitable for publishing articles submitted by engineers working in the industry. The goal is to enrich publications with what is happening in the industry. This is going to be a good source for schools to understand the needs of the industry; this is how the engineering articles can participate in establishing feedback from the industry to colleges.

In addition, to minimize the "Gap" and to establish the missing feedback, PhD students' theses could be utilized. Unfortunately, there is a lack of PhD research regarding the "Gap". To overcome this, PhD students could spend two years of their PhD program working in the industry to collect their observations and daily experience, and present this to the school afterwards. Then, these researches would determine the industry needs and contribute in bridging the "Gap".

The Cooperative Engineering Education (CEE) [14] is one of many excellent educational tools that prepares students to work in industry. However, engineering colleges should extend the CEE program by treating it as feedback to reform engineering education itself. Currently, most schools use CEE as a tool to advance the practical skills of engineering students but there is a limited utilization of CEE to reform textbooks. Thus, it is recommended to use CEE as an additional tool to establish the missing feedback link from the industry to engineering schools and bridge the “Gap”.

Briefly, the purpose of this strategy is to keep improving education at a sustainable pace by utilizing the resources that are collected from the feedback link. We do not immediately expect any drastic change towards a practical-oriented education, rather, a gradual change over decades would be more realistic. Faculty participation and openness are crucial to the reform process. However, faculties cannot be the only source of educational reform. Instead, faculties should reform education according to industry feedback; meaning the industry is the main drive for reform, and not the faculties themselves.

V. CONCLUSION

A strategic initiative to minimize the long-standing gap between the engineering workforce produced by universities and the needs of the engineering industry has been presented. The initiative is mainly designed for bachelor level. The problem with the “Gap” is the absence of feedback from the industry to educational institutions. Establishing feedback is essential for achieving the goals of the proposed strategic initiative. The goals, or the expected outcomes of the proposed initiative, are the following: 1. The current classifications of university majors are not in line with those in the industry. The job titles of engineers in the industry are, for instance, Project Engineer, Maintenance Engineer, Field Engineer, Construction Engineer, etc. which are different from the classifications of universities, which are, for instance, Electrical Engineer, Mechanical Engineer, etc. This problem demonstrates the reason for our first goal, which is to realign the classifications of knowledge taught by engineering schools to match industry needs. 2. The value of an engineer to their occupation is correlated to the quantity and type of their knowledge. However, the aforementioned correlation becomes insignificant once the quantity of knowledge reaches a certain limit — that limit is dependent on the occupational path and type of knowledge. So, the second goal of this strategic initiative is to identify the knee point of specific knowledge for an occupational path. Three things have been proposed in this paper to establish feedback from the industry to educational institutions and create a competitive environment to strive for excellence. The first is to open the door for engineers to write what they see and experience at an industry level in engineering journals. Through their writing, schools will get an idea of what is going on in the industry. Secondly, the accrediting agencies must be involved in the process by giving a higher rank to engineering schools based on what they have done over time to bridge the “Gap”. Lastly, PhD research and CEE programs need to be utilized. For instance, a PhD student could work for a company, then return to school two years later to present their findings and observations. The purposes of CEE programs must be extended as well in order to bridge the “Gap”. This will be a valuable source for building an appropriate curriculum based on the knee points of different fields of knowledge.

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