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A Systemic Approach to Global Competency for Engineers

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Abstract

The purpose of this paper is to outline a systemic approach to global competency for engineers. Using quiz questions used in our *Engineering Cultures* course as a pathway into the problem of global competency, the paper begins by introducing the problem and briefly summarizing the learning criterion and learning outcomes for global competency presented in a forthcoming paper in the *Journal of Engineering Education.* That criterion calls attention to the importance of problem definition in engineering work. Building on the main elements of and lessons learned by NSF-sponsored systemic reform efforts in engineering education in place since 1990s, this paper outlines in detail the following aspects of systemic reform for global competency: 1) unifying *visions and goals*, including high standards for learning expected from all students; 2) a *restructured system of governance and resource allocation*, including a proposed new ABET criterion for global competency; and 3) *alignment among all parts of the system*, including hiring practices, modifications to engineering science and elective courses and textbooks, and accountability mechanisms. After reviewing several approaches to global competency, the paper concludes by asserting that "the ultimate success of methods for achieving global competency will depend both upon their integration across the full range of the engineering curriculum, including in engineering science courses, and upon widespread acceptance among engineering educators of the importance of giving as much weight and time to problem definition as is currently given to problem solving."

Introduction

We begin with a short quiz on problem definition in engineering. The quiz consists of two questions, one on international differences in what is emphasized in engineering work and one on international differences in what counts as engineers. All are true.

The first is an example from World War II. During the summer of 1940, British freighters were sinking, victims of Nazi U-boats. Doubting its survival, the U.K. sent a purchasing commission to U.S. shipyards. A deal was quickly reached, but then all progress came to a stop. To the commissioners' dismay, their ship plans proved meaningless to American engineers, workers, and managers. The entire set of drawings had to be redrafted and hundreds of additional drawings were needed before work could begin on building the ships that would help save the war for Britain. Explain.

Second, in ABET criteria 3a-3k, the ability to apply math and science while understanding professional responsibility is first of the eleven criteria, while understanding of ethics is sixth and understanding of global, societal, environmental and economic issues is eighth. In contrast, in the eight criteria established by JABEE, the Japanese Board for Engineering Education, the ability to apply math and science is third, while an understanding of "social responsibilities" is second and the top position is held by the ability to "consider . . . issues from a global and multilateral viewpoint." Explain

The purpose of this paper is to outline a systemic approach to global competency for engineers. Using the above quiz questions as a pathway into the problem, the paper begins by introducing the problem of global competency and briefly summarizing the learning criterion and learning outcomes for global competency presented in a forthcoming paper in the *Journal of Engineering Education.* That criterion calls attention to the importance of problem definition in engineering work. After reviewing several approaches to global competency, the paper concludes by asserting that "the ultimate success of methods for achieving global competency will depend both upon their integration across the full range of the engineering curriculum, including in engineering science courses, and upon widespread acceptance among engineering educators of the importance of giving as much weight and time to problem definition as is currently given to problem solving." This paper takes the next step.

Global competency, cultures, and problem definition

In the U.S., the problem of global competency for engineers is often presented as a problem of engaging people from different cultures. Downey et al.[1] point out that an important caution to recognize and keep in mind is that a key characteristic of globalization is that it is now difficult to characterize people as members of single cultures.[1] The key point has to do with countries. Statements about the benefits of global learning for engineering students typically locate those benefits in encountering and coming to understand engineers and other potential co-workers who are raised, educated, and living in countries other than their own. Their special educational status is an indicator of the key, defining element in the goal of working productively with different cultures, i.e., learning to engage effectively ways of thinking about and understanding engineering work that differ from your own. Even if other countries do not have single cultures, they nonetheless provide high-probability sites for encountering unfamiliar ways of thinking about engineering work. The additional competency gained from effectively engaging people from other countries is to learn to work with people who *define* problems differently.

The key questions in problem definition include (a) what counts as relevant knowledge, or how engineers, and non-engineers, draw boundaries around their problems?; and (b) who counts as engineers, or how do issues of life and career affect engineering work?

The opening quiz questions provide examples of each of these. In the first question, the Americans were amazed that the drawings the British purchasing commission brought in 1940 did not have dimensions on them. They were British designs, not American-style blueprints. British engineers were creative designers who focused on function and aesthetics. Their boundaries left the specifics of construction to highly-trained and experienced craft workers with whom they worked closely. The blueprint was developed in the U.S. during the 19Pth^{P} century to enable engineers to exert and maintain control over unskilled labor.

The second question alerts us to the strong sense of obligation Japanese workers feel to the *ie,* or household, whether the *ie* is a family home, corporate employer, or nation state. In contrast with the U.S., the recent Japanese interest in accreditation and professional responsibility is a response to concerns about the failure of Japanese corporations to fulfill their obligations. The professional societies are moving in to insure that Japanese engineers fulfill their obligations to the national household.

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[1] This section offer a short summary of Downey et al. 2006.

Overall, the achievement of global competency depends critically on developing the ability to work effectively with people who define problems differently than oneself, including both engineers and non-engineers.

Three elements of systemic reform

As Lucena explains, the concept and practice of systemic reform in science and engineering education was born in *Goals 2000: Educate America Act of 1993*.[2] Since the mid 1990s, the U.S. Dept of Education has defined systemic reform as include "three integral components." These include: "(1) the promotion of ambitious student outcomes for all students; (2) alignment of policy approaches and the actions of various policy institutions to promote such outcomes; and (3) restructuring the governance system to support improved achievement."[3]

In the mid-1990s NSF became the site of systemic reform in science and engineering education. It defined systemic reform as "fundamental, comprehensive and coordinated changes made in science, mathematics and technology education through attendant changes in school policy, financing, governance, management, content and conduct." According to NSF, systemic reform has three interconnected aspects: 1) unifying *visions and goals*, including high standards for learning expected from all students; 2) a *restructured system of governance and resource allocation* that places greatest authority and discretion for instructional decisions on school sites; and 3) *alignment among all parts of the system*, including policies, practices and accountability mechanisms.[4]

Our systemic approach to global competency for engineers follows the NSF model.

Unifying vision and goals

Drawing on the above discussion, the unifying vision is built into the proposed learning criterion of global competency (hereafter CGC): "Through course instruction and interactions, students will acquire the *knowledge, ability, and predisposition* to work effectively with people who define problems differently than they do." This criterion is, in turn, linked to three learning outcomes, which constitute its primary goals:

(a) "Students will demonstrate substantial *knowledge* [or factual understanding] *of* the similarities and differences among engineers and non-engineers from different countries."

(b) "Students will demonstrate an *ability to analyze* how people's lives and experiences in other countries may shape or affect what they consider to be at stake in engineering work."

(c) "Students will display a *predisposition to treat* co-workers from other countries as people who have both knowledge and value, may be likely to hold different perspectives than they do, and may be likely to bring these different perspectives to bear in processes of problem definition and problem solution."

The four primary methods for helping students achieve global competency all depend on international travel. These include: international enrollment, international project, international work placement, and international field trip. To date, the most significant challenge to the methods of international enrollment, international project, international work placement, and international field trip is to increase their sheer scale of participation. At present, fewer than 3% of engineers in the U.S. seek international enrollments [5], and in Europe only 1% of all European engineering students participate in ERASMUS programs.[6] In both cases, participation in the methods of international project, work placement, and field trip likely does not increase this amount to more than 5-6%.

Given limited participation in these experiences, a systemic approach to global competency minimally must seek ways of expanding integrated class experiences, both to provide substitute experiences for those students who cannot afford or who are not inclined to undertake international travel and to further enhance the learning of those who do travel.

Restructured system of governance and resource allocation.

Add ABET criterion 3L

While mainly in the hands of faculty, governance of engineering curriculum is externally influenced by a number of factors, mainly ABET accreditation criteria. To the eleven existing outcome criteria (3 a-k), we propose that ABET adds an additional EC 2000 program outcome criterion (3L) where engineering programs must demonstrate that their students "attain the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do."

In addition to challenging engineering programs to address the CGC, 3L also enhances criterion 3E that calls for programs to demonstrate that their students "attain an ability to identify, formulate, and solve engineering problems." Since 3E takes place within the context of the 'engineering problem-solving method' where most problems are given in a textbook or exam, identification, formulation, and solution does not include problem definition. Hence 3E leaves out problem definition. 3L brings it back.

Other benefits stem from adding 3L. In their study of student performance on EC 2000 criteria 3.a –k., Linda Strauss and Patrick Terenzini of the Center for the Study of Higher education at Penn State found out that when asked about their performance on criteria 3a-k, respondents failed to differentiate clearly between 3H "understand the impact of engineering solutions in a global, economic, environmental, and societal context" and 3J"knowledge of contemporary issues."[7] By clarifying what it means to be global, 3L also helps minimize confusion between criterion 3H and criterion 3J.

3L could also contribute to mobility and understanding among engineers. ABET criteria is becoming widely considered and adopted abroad as reflected by the existing Washington Accord and the proposed Engineer of Americas initiative, both aimed at creating quality assurance in engineering education using ABET criteria to promote mobility across countries. Without 3L, a potential result of these initiatives is that engineering programs all over could end up observing similar outcome criteria but engineers from different countries will not understanding each other. 3L minimizes this risk

Modify funding policies

Engineering education community has become reliant on NSF funding for their curricular, programmatic, and reform activities. Hence we propose to add the CGC to the criteria that determines how some of this funding is allocated. To exiting NSF evaluation criteria, the CGC can be applied to evaluate proposals such as those at NSF's Developing Global Scientists and Engineers Program. Hopeful PIs will have to demonstrate how the project will improve faculty and student's *knowledge, ability, and predisposition* to work effectively with people who define problems differently than they do.

The CGC can also be added to evaluation criteria of existing faculty fellowships such as the Boeing Welliver Faculty Fellowships or those funded by NASA, ONR, USAF. For example, for the Boeing Fellowships, in addition to demonstrating teaching experience, commitment to undergraduate engineering education, motivation to improve teaching and learning, and acquire a better understanding of the practice of engineering, applicants would have to demonstrate how the fellowship will improve their *knowledge, ability, and predisposition* to work effectively with people who define problems differently than they do and how they will incorporate these into their classroom.

Introduce faculty development

Faculty development workshops can be used to help faculty connect research on student learning, teaching methods, content knowledge of Engineering Cultures, and assessment practices. The model developed by ASEE, CSM, and the University of Minnesota in their project *Rigorous Research in Engineering Education: Creating a Community of Practice* serves as an example where "powerful partnerships are formed as information about how students learn and teaching methods that support students' learning are coupled with the content knowledge of practicing engineering educators." [8] We could follow this model to train engineering and non-engineering faculty to conduct rigorous research related to engineering cultures and write/implement textbook problems and case studies such as those described above. Potential workshop participants could include (a) educators at engineering schools with strong commitment to international engineering education (e.g., Purdue, Rhode Island, Cincinnati, Georgia Tech, Michigan, Milwaukee School of Engineering, WPI) (b) engineering schools with strong commitment to interdisciplinary science and technology studies (STS) (e.g., North Carolina State, Cornell, MIT, Rensselaer, Virginia Tech, UVA); and (c) engineering schools with strong commitment to humanities and social sciences (e.g., Harvey Mudd, Smith).

Practices, policies, and accountability mechanisms

The following is a survey of different areas in the system of engineering education that could undergo reform to integrate a criterion of global competency.

Global competency as a hiring criterion

To promote these outcomes in engineering education, we recommend that employers consider incorporation the above CGC as a criterion for assessing engineering graduates as job candidates. In other words, candidates would be asked to show evidence that they possess the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do."

Existing hiring criteria for prospective engineering employees include type of degree, school, GPA, work and project experience, performance during an interview, extra-curricular activities, and in some cases international experience. Although international experience is gaining importance in hiring, such does not necessarily translate into global competency. In some cases, the ability to work alone is considered an important competency for international assignment. As the director of recruitment at a major U.S. aerospace company once reported in an interview: "When we hire US engineers to be assigned to Brazil to work in our contracts with Embraer, we look for engineers *who can work alone* and without direction because we don't have a big operation down there." Surprisingly, the director assumed that her solitary U.S. engineer would know how to define and solve problems with their Brazilian counterparts. But this assumption could be problematic since engineers educated in different countries learn to value different configurations of engineering knowledge.

To prepare students to address this new hiring criterion and prepare recruiters to assess student progress toward its achievement, innovations must take place across curricula.

Modifications to engineering science courses and textbooks

The adoption of a CGC would not require the dilution of rigorous technical curricula. Quite the contrary. Including international contrasts in historical context in engineering science courses can help these courses achieve "relevance" in the minds and hearts of students. For example, in introducing the concept of stress in mechanics of materials, the origins and contrasts between what counts as engineering in Germany and France could be highlighted while contributing to students' understanding of key principles and calculation methods. Prior while being introduced to Mohr's circle for plane stress in a beam, students can learn that what counts as engineering in Germany is the application of math and science to industrial problems through the example of Otto Mohr (1835-1918), his attendance to a Higher Trade Institute (Hannover), his work for the Hanover and Oldenburg state railways (promoted by the earlier attempt to create a customs union (Zollverein) among German lands), and his interest in understanding and calculating plane stresses on railroad and bridge elements which eventually led to the development of the Mohr Circle. Similarly, prior to being introduced to Poisson's ratio, students can learn that what counts as engineering in France is math and science theory for the organization of society through the example of Simeon Poisson (1781-1840), his ascendance in French society as a graduate and teacher of the Ecole Polytechnique, his mathematical work in celestial mechanics at the Bureau des Longitudes, and his civil service at Ecole Militaire.[9] A similar contrast can be used in thermodynamics to highlight differences between what counts as engineering in France and Britain with the examples of Sadi Carnot (1796-1832) and William J. M. Rankine (1820-1872).[10]

In order to reinforce the CGC through homeworks and exams, textbook problems can be written to incorporate historical context and international contrasts. For example, a mechanics of materials textbook could include such end-of-chapter problems as: "Promoted by the expansion of customs union (Zollverein) among German lands, railroads were crucial in the unification of Germany in the second half of the 19th century by mobilizing raw materials and finished products across diverse German lands. Contributing to this economic unification through his work for the Hanover and Oldenburg state railways, Otto Mohr developed the 'Mohr Circle' to analyze plane stresses on many railroad and bridge elements. Using Mohr's circle, calculate the stresses on the bridge beam shown in fig…"

Modifications to elective courses

Non-engineering science courses in the engineering curriculum can incorporate the CGC by using case studies of conflicts in engineering perspectives. Consider, for example, two pilot case studies now under development, following Yin.[11] Horkey describes French engineering students encountering U.S. engineering curricula at the Colorado School of Mines (CSM) and highlights the tensions between a French engineering emphasis on mathematical derivations and a U.S. emphasis on textbook problem-solving. French engineering students were greatly surprised at the relative lack of mathematical content in engineering courses.[12] Bauer describes encounters and differences between engineers educated in Germany and those educated in the US in an environmental engineering program at CSM. In addition to elective courses, the first case study could be used in engineering mathematics courses to illustrate different perspectives on the mathematical content of engineering courses and approaches to problem solving, and the second in environmental engineering courses to illustrate the difference between engineering education in Germany and the U.S.[13] Through previous research, we have on file more 150 interviews with engineers from many countries, which provide the basis for a growing corpus of cases studies in a project we call "Engineering Encounters." which will be used to develop more case studies for specific uses.

Another potential contribution to systemic reform practices would be to make available an Engineering Cultures textbook with content and problems aimed at enhancing student advancement toward global competency. This textbook can be modular, hence facilitating the use of separate chapters by engineering schools with interests in specific countries or regions. Consider the following outline:

Chapter	Title	Sections
1	Can Engineers Deal with Different Perspectives?	Introduction: What images of engineering challenge you? Culture as dominant images rather than shared beliefs Dominant self-image of engineers: rational problem solver, no politics The cultural politics of engineering problem solving
2	Images on the job: Economic competitiveness as a Western cultural problem	The dominant image of competitiveness The dominant image of the American individual The 'strong culture' movement and normative control Encountering and internalizing images How the strong culture movement produces ambiguity Problems and case studies
3	Japanese perspectives: Be sure you suffer enough	Social and political history of Japan The dominant image of harmony Ie, ki, and kokoro: dominant images of Japanese personhood Changing dominant images: economic restructuring, multinationals Working as an engineer in Japan Problems and case studies
4	Soviet and Russian perspectives: Ball-bearings-for-paper-mills engineers	Dreams of an alternative to capitalism: Marxism, socialism, and anarchism Competing images of the Soviet nation-state: the Communist Party, Leninism, and Stalinism Dominant image of engineers under Stalin: Ball-bearings-for-paper-mills engineers Dominant images of engineers during the Cold War Problems and case studies
5	French Perspectives: What counts is mathematical knowledge	Social and political history of France The engineers of the Revolution The dominant image of mathematical theory

		Engineering Education in France Working as an engineer in France Problems and case studies
6	British Perspectives: What counts is craftsmanship	Social and political history of Britain Engineers as apprentices during the Industrial Revolution The dominant image of craftsmanship Engineering education in Britain Working as an engineer in Britain Problems and case studies
7	German Perspectives: What counts is precision technics	Social and political history of Germany The rise of engineering in Germany The dominant image of precision technics Engineering education in Germany Working as an engineer in Germany Problems and case studies
8	US Perspectives: What counts is balance	Brief history of engineering schools/disciplines in the US The rise of the corporation as the place for engineering employment Origins of the tension between 'design' vs. 'manufacturing' Technical and non-technical problem solving at the same time The visible 19^{th} c engineer vs. 20^{th} c invisible engineer Problems and case studies
9	Latin American Perspectives	Social and political history of Latin America Colombia: images of regionalism and national development Brazil: images of empire, orden y progreso Mexico: images of development in the shadows of the Northern Neighbor Competing images in the Americas
10	Other Asian Perspectives	Social and political history of South East Asia Korea China India Competing images in Asia Problems and case studies

Problems at the end of every chapter could allow students to apply their knowledge of the differences of what counts as engineering in various countries. For example, a contemporary problem to assess students' ability to apply their knowledge of the differences between British and U.S. engineering could read as follows: "U.K. and U.S. engineering students work in two national groups in a Global Engineering project at Boeing designing the exhaust nozzle for the Apache helicopter. U.S. students divide their work according to engineering disciplines while each U.K. student is expected to complete every step of the design process, e.g., pre-lim design, multiple designs, cost and manufacturing assessment, design selection, etc. Explain the difference of approaches based on the historical and cultural dimensions of engineering education in each country."

Conclusion: Is a systemic approach to global competency feasible?

In the mid 1990s, the engineering education community identified the NSF Engineering Education Coalitions and ABET 2000 as the mechanisms for leading systemic reform in engineering education.[14] However, according to a review of the Coalitions conducted by a consulting firm, the goal of systemic reform remains largely unfulfilled:

> The Coalitions program has had many important impacts during the first five years but these cannot be said to be 'the comprehensive and systematic new models for engineering education reform' anticipated. Most impacts had been intra-institutional, indeed, intra-disciplinary. Participating institutions cover less than 1/3 of engineering faculty and ¼ of engineering students in the Unites States, and not all of their engineering faculty and students participate in Coalition-influenced courses…Dissemination of new structures and approaches affecting all aspects of undergraduate engineering education was not successful. Most courses and initiatives were idiosyncratic in nature and difficult to implement elsewhere, even within the participating institutions.[15]

In other words, while the model of targeted innovation followed by dissemination may be a necessary feature of systemic reform in engineering education, it is not sufficient. We conclude that a systemic approach to global competency can be successful only through diligent attention to key social and organizational dimensions of engineering education. Minimally these include growth in grassroots support, strategic mobilization of networks, cultivation of energetic leadership, persuasive responses to resistance, and flexibility of vision.

One of our first challenges is to identify the kind of change that we advocate, the underlying assumptions that we make, and the actors who could implement our systemic reform.[16] Our proposed systemic reform has great potential to be a *grassroots change* because of the significant number of faculty, at different types of engineering schools occupying different levels and having different relationships to the core of the engineering curriculum, deeply interested in global competency. One has to look no further than the increasing attendance to and growth in number of international engineering education conferences. ASEE and SEFI conference sessions, where activist educators present initiatives on international education, have grown significantly over the past five years. The International Colloquium on International Engineering Education is now on its eight edition.

We also believe that our proposal can only be successful with the help of existing *activist networks and groups* committed to enhance international education in the engineering curriculum. After her return from France, a Global Engineering Education Exchange (GE3) student from the US could not understand the elitist behavior of the Ecole Polytechnique (EP) graduates that she encountered during her studies in Paris. After taking the EC multimedia module on France, she clearly understood that EP graduates enjoy great prestige in French society due to their expected role in planning and managing the government. Elitist behavior of EP graduates now seemed obvious to the US exchange student. This systemic reform will rely heavily on networks like the GE3 Program who by adopting the CGC can enhance exchange students' understanding of what counts as knowledge and who is an engineer in their host country. By increasing the relevance of their exchange programs to global competency, the GE3 might also improve the imbalance that exists between the lesser number of US engineering students studying abroad and the higher number of foreign engineering students who want to study in the US. Other networks like ASEE Liberal Education Division (LED) can enhance their visibility by adopting, promoting, and even improving the CGC. After many years of commitment to ethics and communication education, LED members can contribute to expanding the small efforts that we have begun in CGC-related curriculum development, assessment, and cross-cultural communication.

This systemic change will also rely on *availability and dissemination* of content and best practices to the grassroots reformers and networks above. We have taken a small step in this process by placing multimedia content on the web (www.conted.vt.edu/ecs/) and have plans to collaborate with others in the development of case studies, a textbook, and faculty workshops. Success will depend on others developing and disseminating CGC-related materials, for example in topics such as engineering ethics, technical communication, and design across cultures. Publishers have much to contribute and gain from this untapped market for books and other materials related to CGC.

Furthermore, we acknowledge that our proposed systemic reform cannot be accomplished without *value-driven institutional leadership*. Visionary leaders in engineering education deeply committed to global competency such as Jack Lohman at Georgia Tech, John Grandin at URI, and Russ Jones at ASEE can enhance institutional ability and responsiveness to change. Other engineering deans and provosts could emulate these examples and create incentives at their institutions for faculty and administrators who embark on curricular and programmatic reform based on CGC.

Resistance to organizational change has also been identified as an important factor impeding success in systemic reform.[17] In this case resistance might come from faculty who feel threatened about the loss of rigor or credits in the technical curriculum if more content related to the CGC is introduced. Overcoming resistance is firstly about effective argument via elegant simplicity, and then persistence in making the points. We have made an argument for CGC [1] but rely on committed faculty and administrators to continue making the case for global competency. Reluctant faculty might find comfort in faculty workshops as they learn engineering cultures content relevant to their engineering courses and effective teaching methods for delivery.

Other dimension that has been identified as barriers to systemic engineering education reform is rigidity in vision.[17] According to Eckel and Kezar the key is to have a *flexible vision* where a direction and a rate of change are first articulated but allowed to be modified according to specific circumstances..[18] By proposing the CGC, we have taken a small step in this direction but flexibility of vision minimally means that more than one conception of global competency can co-exist, and that all committed parties should be open to change. We welcome revisions, additions, and transformations to the CGC, particularly as activists realize the implications of adopting the CGC in their own institutional context.

The dominant spirit in this systemic reform must be of cooperation rather than competition, for the challenges we all face are greater than the challenges each poses to others.

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