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Globalization of Problem-Driven Learning: Design of a System for Transfer Across Cultures*

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Innovative learning pedagogies are increasingly used in the west towards equipping graduating engineers with the set of skills and competencies essential for the engineer of the 21st century. The successful globalization of such pedagogies in the developing world is key to educational reform and the building of sustainable knowledge-based economies. In this paper, we report on the development of an exportable model for effective Problem-Driven Learning (PDL), a problem-based learning pedagogy, transfer across cultures. The system is demonstrated using a case study in transnational exchange and cooperation between Georgia Tech (GT) in Atlanta, Georgia, USA and Khalifa University (KU) in Abu Dhabi, UAE around the design of a biomedical engineering course delivered using PDL. Although the underlying framework of the innovative pedagogy was adopted from GT, various local elements were implemented to ensure cultural compatibility. The main hypothesis postulates that cultural consideration is critical to the successful globalization of a learning pedagogy. Cultural relevance and sensitivity are critical to effective cross-cultural transfer.

Keywords: Problem-Driven-Learning (PDL); engineering education; cross cultural transfer; 21st century skills; Globalization

1. Introduction

1.1 Engineering education and the skills gap: a global phenomenon

Engineering education stakeholders, from academic institutions, educators, and alumni to private sector industries, governmental education agencies and accreditation bodies universally agree that current engineering graduates lack the critical skills essential for the 21st century dynamic world which is rapidly being transformed by information explosion and scientific and technological advances. Today's practicing engineer operates under multifaceted global, cultural, and business constraints, and hence needs a set of tools, skills and competencies to cope and compete within the boundaries of such unprecedented grand challenges. The National Academy of Science in the USA identifies five essential 21st century skills: *adaptability*, *complex communication/social skills, non-routine problem-solving, self-management/self-development* and *systems thinking* [1]. These competencies are reiterated in the UNESCO's report "Learning: The Treasure Within: Education for the Twenty First Century" [2] and in a recent European Community's report which identifies eight key competences essential in a knowledge-based society [3]. The EU report emphasizes that these skills are not only critical in providing the flexibility in the labor force through allowing for quick adaptation to dynamic changes, but also serve as foundation pillars for innovation, productivity and competitiveness; proficiencies highly valued in a global world that has been encountering economic challenges in many of its countries [3].

Research shows that the inadequate preparation of engineers in key competencies in fact extends globally. A recent UNESCO report (*Skills Gaps Throughout the World: an analysis for UNESCO Global Monitoring Report* [4]) warns that skills gaps are constraining companies' ability to grow, innovate, deliver products and services on time, meet quality standards and meet environmental and social requirements in countries where they operate. The report identifies the lack of available talent and trained resources in the Middle East as the greatest threat for sustainable development of the region. Gulf leaders are among the least satisfied with the supply of employable graduates including engineers, with only 37 percent citing their satisfaction [4]. Employability skills were classified into four categories (technical, cultural, interpersonal, and intrapersonal) and included fifteen specific skills: *independent task execution; appropriate approach to problem solving; ability to monitor and evaluate own activities; ability to relate specific issues to wider contexts; ability to apply knowledge to new situations; ability to devise ways to improve own actions; ability to deal with different cultural practices; openness and flexibility; negotiation and mediation skills; self motivation and initiative; ability to network; creativity and innovation; ability to relate to a wide range of people; team participation; and sense of identity and self confidence* [4]. Misalignment between education and employers' needs was indicated as one of the main reasons behind the skills gaps.

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The above data clearly shows that in spite of the improvements to engineering education during the past two decades, the majority of engineering curricula throughout the world are still not providing the skills and expertise required to tackle the complex modern engineering problems. From the perspective of engineering educators, critical improvements are warranted on three different levels: placement of courses in engineering curricula (When), content (What), and instructional pedagogy (How) [5]. For example, current engineering curricula, delivered by the majority of institutions worldwide including the Middle East and the UAE, continue to follow the traditional science model of engineering education in which the first two years are typically devoted to basic sciences and mathematics, with minimal exposure to "real-world" engineering problems [5–8]. Furthermore, engineering curricula continue to be mostly delivered by traditional didactic passive lecture mode in which instructors start with theories and mathematical models, and then move to textbook examples, which may or may not ultimately extend to real world practical applications [9]. The combination of the traditional model of engineering education, which clearly delays student exposure to engineering integrative thinking and experience, with passive course delivery leads to the current mismatch between the students' skills and the emerging complexities of modern engineering systems [10]. Research in fact shows that students will not develop the aforementioned competencies by following mostly theoretical, disconnected curricula while sitting passively in lecture halls, taking notes and memorizing content [11–12]. Even more interactive methods such as Personal Response Systems or Student-centered Active Learning Environments for Undergraduate Programs (SCALE-UP) [12], both of which promote greater student interaction, are not specifically designed to help students develop these competencies because the nature of the problems given to students in traditional engineering classes, while a first step in becoming a successful engineers, are not sufficiently complex to allow students to practice essential 21st century skills [13–14]. These challenges in developing countries, such as the United Arab Emirates (UAE), have more severe implications, given that the industrial sector is in its infancy, and hence has an even higher need for innovators, problem solvers, critical thinkers, and independent learners [13].

Engineering education in specialized multidisciplinary fields such as Biomedical Engineering (BME) poses another dimension of challenges. The field of Biomedical Engineering (BME) lies at the intersection of engineering, medicine and the biosciences. As such, in addition to the typical challenges mentioned above, biomedical engineering education entertains its own unique challenges. Newstetter et al. [11] summarize the challenges as ones encountered on two main fronts: the educator front and the student front. From the perspective of educators, biomedical engineering education needs to bridge the gap between engineering and medicine and hence must combine the design and problem solving skills of engineering with medical and biological sciences knowledge and skills. And yet, to date, very few textbooks specifically targeting BME exist at the undergraduate level. The learning challenges on the student front are significant. Learners must master three traditionally distinct intellectual faculties: (1) modeling and quantitative skills required for engineering; (2) qualitative systems analysis skills integral to the life sciences; (3) clinical sensibilities inherent in medicine. It is therefore obvious that biomedical engineering educators need to foster in students the cognitive flexibility inherent in true integrative thinking and system analysis in order to embrace the merging of these distinct practices and historically-separated disciplines [11]. An additional set of challenges in the highly interdisciplinary biomedical engineering education stems from the dynamic nature and fast pace of evolution of this young discipline. Educators and students alike operate in a discipline with continuously shifting grounds and highly dynamic boundaries and constraints. The typical biomedical engineer of the 1970's and 1980's whose main training was in electrical or mechanical engineering with a few "picked up as needed" courses in biology and physiology did not need the skills crucial for today's tissue engineer who works on designing entire organs from stem cells and hence faces a whole range of engineering, biological, clinical, and ethical complexities. The 21-century set of skills and competencies is not only critical here for innovation, productivity and competitiveness, but more importantly for maintenance and enhancement of the ultimate machine- the human body.

1.2 Problem-Driven Learning (PDL) towards bridging the skills gap

In response to the need for fostering the critical skills for successful modern engineers mentioned above, various pedagogical student-centered learning models have started to be incorporated into engineering education. These models encompass a wide spectrum of pedagogies ranging from discovery learning, and case-based learning to problem and project-based learning, active and cooperative learning and just in time lectures. The main feature shared by these models is the presentation of a specific challenge or complex problem to the students as the starting point of the learning process, after which they are coached to self-learn upon recognizing the need for theories, facts, skills and concepts [9]. Learning contexts that enable rich peer interactions and learning tasks the present students with real world, complex, ill-posed problems produce the most substantial learning gains [13].

Problem-based learning (PBL), as defined by H.S. Barrows, one of the pioneers who developed and implemented PBL in medical education over three decades ago, is the learning method based on using problems as a starting point for the acquisition and integration of new knowledge [14]. A pedagogy centered on problem solving of complex, open-ended, ill-defined and ill-constrained problems, PBL inherently aligns with engineering, a field where complex authentic problem solving is a main pillar. As such, it offers engineering educators innovative and effective means to successfully engage students deeply with content [15], to apprentice them to the practices of a particular community [12], to allow them to practice a specific skill set such as spoken and written communication [16–17], and more importantly to empower them to assume responsibility to be self-directed and life-long learners [16–19].

The adoption of PBL as a learning pedagogy in engineering education was greatly motivated by the 1997 National Science Foundation (NSF) report (*Systemic Engineering Education Reform: An Action Agenda*) [20]. The report recommended reform in engineering education particularly stressing teamwork, better industrial links, and the interjection of problem/project based learning techniques [20]. Various researchers/engineering educators reported on the implementation of PBL as a pedagogical model. Huang et al. [21] compared traditional pedagogies, such as subject based learning, cookbook laboratories, and group work, with non-traditional active engagement pedagogies, such as problem-based learning, project-based learning, cooperative and collaborative learning. They also studied mixed learning methods including subject + project assisted and subject + cooperative learning models. Four main factors were used to evaluate the risks and benefits of a particular learning pedagogy, including, student factors, instructor factors, course factors, and institution factors. Their results showed that while both traditional and non-traditional pedagogies have advantages and disadvantages, it is generally favorable to incorporate active learning components in engineering education as they allow for enhancement of nontraditional skills. Kou and Mehta [22] used PBL combined with the Lego RCX System in an Engineering Measurements course as part of the Mechanical Engineering curriculum at North Dakota State University. Their two-year consecutive study used three different teaching methods: (1) traditional; (2) PBL; and (3) combined. Their results showed that the PBL method (implemented partially or fully) significantly improved analytical and open-ended problem solving skills, cooperative team work skills, as well as written and communication skills. The effects of team-based, project-based freshman design course at Pennsylvania State University on student intellectual development were quantitatively measured by Marra et al. [23] using the Perry scheme. The Perry model mainly suggests that the students' cognitive processes develop gradually over time and could be quantified using 9 levels of increasing complexity and maturity of intellectual development. The design experience correlated positively with enhanced students' intellectual development. Brodeur et al. [24] described several problem-based learning experiences in undergraduate aerospace engineering at the Massachusetts Institute of Technology (MIT). They recommended the vertical integration of PBL across all four years to provide a natural progression from structured problems, which require high levels of faculty direction and support, to unconstrained and more complex problems that resemble real life situations. Their results reflected that students at MIT who underwent the PBL learning model reported a greater understanding of core science and engineering courses, found learning more interesting and engaging, and established better connections between their education and real-world applications.

In our context, Problem-driven learning (PDL) can be used interchangeably with problem-based learning or PBL. The word "driven" in PDL is used to replace "based" in PBL in order to emphasize the central role of complex problems in initiating and driving the learning process. This term was indeed developed by our research partners at Georgia Institute of Technology in Atlanta (GT) as they were investigating the processes of reasoning, problem solving and learning in university research labs that are considered authentic sites of interdisciplinary practice [25–26]. Over the last ten years, they have investigated a tissue-engineering lab, a neuroengineering lab and two integrated systems biology labs using ethnographic research methods. The findings on learning in those sites were translated into new models for engineering education [11]. They found in these sites of authentic engineering activity that learning is powered by the need to solve complex problems. Problem-driven learning fuels advances in knowledge and lab breakthroughs. However, the laboratory problems look nothing like textbook problems. They are complex, ill structured and ill constrained. They require the integration of knowledge and skills across the bioscience/

engineering divide. Adapting to new and changing conditions both in terms of personnel, problem types and the ever-present impasses encountered in frontier science is a fact of life. Researchers need to navigate what, when and how they learn; they work collaboratively when the intractability of the problem demands a collection of heads and hands. Investigations of these laboratories illuminated why BME majors need to practice early and often the skills of tackling, defining, constraining and working through complex, interdisciplinary problems to be able to effectively participate as complex problem solvers in industry, clinical settings or research. GT consequently developed an introductory course in biomedical engineering with the mantra: *Empower students to be agents of their own learning who are fearless in the face of a complex problem.*

1.3 PDL cultural transfer

The pace of pedagogical innovations in education in the Middle East, particularly in engineering, has been significantly slower than the west [12–13]. This is partly due to relatively young higher education institutes in many of the countries such as the UAE, the diversity of education contexts and learning approaches, and the scarcity of educational reform models specially designed for the developing world [13, 27]. The literature shows no homegrown cultural pedagogies and few examples of pedagogy transfer from the west [12–13, 27–28]. There is no clear evidence whether the imported models/pedagogy transfers are truly applicable, and more importantly what elements need to be considered to ensure compatibility and success. In fact, experts agree that the cross-cultural applicability of western models has not been fully established in diverse settings [29–30]. In their recent article on the globalization of problem-based learning for medical education, Frambach et al. [31] investigated whether or not and how cultural factors affect self-directed learning (SDL), one of the fundamental attributes of PBL. They examined SDL in medical schools in three different cultural contexts: East Asia, the Middle East and Western Europe. The authors found that various cultural factors posed particular challenges to SDL. For example, cultural factors of uncertainty and tradition constituted a significant challenge in Middle-Eastern students, while hierarchy affected Asian students and achievement impacted both groups. They concluded that globalization of educational pedagogies should not necessarily assume uniform processes, and hence culturally sensitive alternatives need to be developed [31] Newstetter, Khalaf and Ping [12] reported on a three-site, collaborative experiment in using problem-driven learning in an introductory engineering class in three different sites: United States, Abu Dhabi and China. Their paper discussed the development and exchange of problems across the three sites, (2) the different constraints and realizations of the problem- driven approach at each and (3) the student experiences and outcomes of using problem-driven learning as a transnational pedagogy for the 21st century engineering education [12]. A recent article by Khalaf et al. [13] used three case studies to investigate how pedagogical innovations and engineering educational reforms designed for western cultures function when implemented in a Middle-Eastern novel context. Based on three case studies, the authors found that problem-based, project-based and collaborative learning modalities can be implemented with some modification to their core features and significant learning gains relative to traditional lecture-centered versions of the same courses. While the literature documents random experiments of implementing western educational practices here and there, there is little work done on cultural applicability of these educational models, particularly within engineering education context and framework. The question of how will pedagogical innovations and educational reforms designed for western cultures function when implemented in a novel context, such as the Middle East, and what refinements need to be adopted in order to optimize the benefit of such innovations remain largely unanswered. More importantly, there is a clear lack of standard models or systems that facilitate and enhance the efficacy of culturally sensitive pedagogy globalization. *In this work we present a model of an exportable system for effective learning pedagogy transfer, particularly Problem Driven Learning (PDL), across cultures. The model is built around using a mature, well-developed and tested learning pedagogy as a primary framework, while integrating culturally sensitive and relevant elements as needed. A case study of a PDL-based biomedical engineering course developed in collaboration with Georgia Institute of Technology in the U.S. and implemented at Khalifa University in Abu Dhabi is used to illustrate the cross- cultural transfer model.*

2. PDL model at GT—the development of "generic" cross-cultural core problems

The development of a problem-driven learning curriculum at Georgia Tech in Atlanta began in the year 2000 as the newly founded Department of Biomedical Engineering was accepting its first cohort of PhD students. The PDL graduate course was modeled based on the anchored instructional approach found in Medical PBL designed to support free inquiry and the development of diagnostic problem-solving skills. In the BME context, the course was based on six problems representative of the different branches of biomedical engineering and was designed to expose the students to the fast paced nature of technological advances and the process of innovative problem solving across disciplinary borders. The course also required students to engage in integrative thinking across disciplinary lines; a critical key for success for Biomedical engineers and researchers, while helping them build the inquiry skills foundational to life-long learning.

Inspired by the success of the graduate course, an undergraduate course titled *Problems in Biomedical Engineering I* was piloted towards fostering integrative thinking and cognitive flexibility; much needed attributes in a multidisciplinary field such as biomedical engineering. The course was designed to systematically organize and sustain a learning environment referred to as a cognitive apprenticeship [10, 26]. Analogous to the novice in a traditional apprenticeship, the learner engages in a set of repeated learning interactions that duplicate the activities of a more experienced practitioner but with the guidance of a facilitator. The facilitator, in a manner emulating a master tradesman, models and coaches or scaffolds expert problem-solving strategies within the group. The learner, consequently, repeatedly practices the integrative reasoning skills fundamental to complex, open-ended problem solving while building a knowledge base in engineering and the life sciences [10]. In the Georgia Tech program, the basic learning unit of the PDL approach is the tutorial group, comprising six to eight students randomly assigned in a group and a facilitator/tutor. The facilitator is not an expert that provides information or directs the group towards a solution, but rather a guide who asks in depth probing questions at the process level in a guidance or scaffolding support role. Specially designed classrooms with four writable walls, which only accommodate 10 people were specially designed for these groups which meet twice weekly for an hour and a half each session. The PBL session follows a protocol in which students articulate and apply what they know or have learned through out-of-class self-directed inquiry, use this new information to generate hypotheses, models and ideas, and identify new areas for inquiry to be conducted before the next session. These activities model the reasoning strategies the students are working to master. Fig. 1 depicts this interactive learning cycle [10].

The PDL process cycle as shown in Fig. 1 enables the students to identify what they do not know but need to know to solve the problem. This identification process is critical as it empowers them to take ownership of their own learning and recognize the main points for inquiry on their own rather being on the receiving end characteristic of the traditional learning approach. The iterative process allows the students to emulate the real-world engineering process as they work in multidisciplinary teams to repeatedly define, formulate, analyze, solve and disseminate the knowledge of complex problems.

A fundamental pillar in successful PDL implementation is problem authenticity, complexity and fidelity. The problems in PDL are designed to present minimal information. This minimalistic problem presentation approach mimics a typical vague client statement in the industry, a doctor's non-technical problem formulation, a CEO's big picture idea of a project, etc. The goal is to motivate

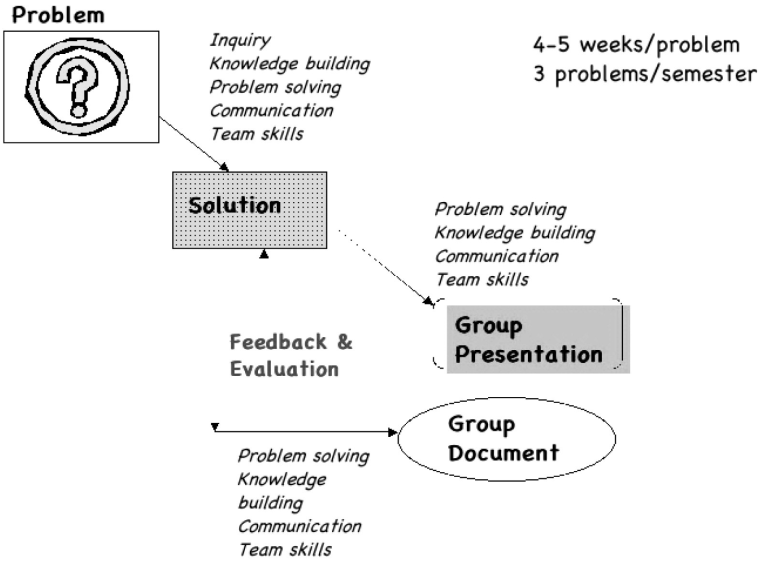


Fig. 1. The PDL Process Cycle [11].

and engage the students since the problems represent real-world, complex challenges, and not a theoretical superficial classroom exercise. More importantly, the minimalism in the problem statement promotes self-directed inquiry, which is fundamental to students developing effective and efficient research strategies. The problems are also designed to be open-ended, ill structured and poorly constrained, features typical to real-world problems. Such features help students develop expert reasoning strategies, as the tutorial group repeatedly practices formulating, constraining and analyzing problems towards crafting logical and appropriate tracks towards optimal solutions. The open-ended structure of the problems also allows each student in the tutorial group to identify areas of inquiry for which she/he is responsible to the group, again emulating real-world engineering via project management and task allocation techniques. Finally, PDL problems are designed to address timely and relevant topics in order to engage and motivate students while introducing them to current problems of multidisciplinary interest. And most importantly for BME, problems are designed to enforce disciplinary integration. Over the years, a data base of problems was developed at Georgia Tech, run and analyzed for the freshman level course until a stable set of three were established that serve specific, desired learning goals. The problems were designed to anchor various kinds of knowledge acquisition and skills development. Specifically, the learning outcomes for the course address four main skill areas: inquiry skills, problem-solving skills, knowledge building skills and team skills (Table 1).

The three problems presented during the problem cycle work interactively towards the development/enhancement of the four skills mentioned in Table 1. As such, three generic problems are designed as *core problems*, with the possibility of changing the topic, relevance, currency, and complexity as needed by affixing particular *skins* to these cores. For example, the first problem typically focuses on screening in the context of particular disease. The problem highlights issues of sensitivity/specificity (probability) in health screening, issues of scale in the context of disease, and the development of quantitative methods of analysis for evaluation/decision- making. A significant intended learning outcome for the whole course generally, but this problem very specifically, is the development of efficient/effective inquiry skills. Each term, a new disease can be explored. Generally cancer of one kind of another has been used but more recently endometriosis and sickle cell disease have been explored. The second problem has experimental design at its core and the third has mathematical modeling and computer simulation. These core problems are designed to offer enough flexibility that each semester is very different for both students and faculty. For example, one semester students might determine through modeling and simulation whether an outbreak of an infectious disease could occur on campus and whether particular measures would be effective in stopping its spread, while the next semester they might look at the potential for experimental viral traps to halt the spread of HIV. This potential to redo the core problem each term with a different story line keeps the course fresh and current for both faculty and students. Since faculty are not expected to teach the material but to facilitate the problem solving process, they find the kinds of interactions with their students to be very similar to those they have with their graduate students during lab meetings [10].

3. Cross cultural globalization—the development of "cultural-specific" skins

The infrastructure of the PDL model adopted at the Biomedical Engineering Department at Khalifa University in Abu Dhabi is primarily based on the one designed by GT in terms of pedagogy, overall learning outcomes, and overall general course structure. Similar to the GT model, the KU model uses the three-problem structure described above. The "*core*" of these problems was retained, considering the maturity of the problem database developed at GT and the evidence of benefit in terms of student learning outcomes. On the other hand, what we refer to as "*skins*" or outer shells affixed to these open-ended, ill structured and poorly constrained core problems were specifically designed to "custom–fit" the KU and the UAE culture. In the process of implementing the Georgia Tech PDL model, it became very quickly clear that a purely western "cut and paste", one size fits all model will not work effectively in different cultural and traditional settings. While this misalignment has no proven theoretical foundation, it soon became evident in the process of the iterative design of the course. Issues ranged from problems that are irrelevant or inappropriate for the culture, to focusing on particular skills critical for the development of that culture and to cultural specific assessment, facilitation and team formation. This allowed the authors to identify the main elements that should be considered in developing an effective cross cultural transfer model. While the model was mainly built based on PDL as pedagogy, the elements incorporated are modular enough to span general issues encountered in the implementation of other educational pedagogies.

Table 1. Skill-Based Assessment Rubric Developed at Georgia Tech and Adopted at Khalifa University

	EXCEPTIONAL (A)	**PROFICIENT (B)**	**FAIR (C)**	**POOR (D)**
INQUIRY SKILLS	• Actively looks for and recognizes inadequacies of existing knowledge • Consistently seeks and asks probing questions • Identifies learning needs & sets learning objectives • Utilizes advanced search strategies • Always evaluates inquiry by assessing reliability and appropriateness of sources	• Recognizes inadequacies of existing knowledge • Generally asks probing questions • Utilizes appropriate search strategies • Mostly evaluates inquiry by assessing reliability and appropriateness of sources • Utilizes effective search strategies	• Occasionally claims areas of inquiry but mostly takes what's left • Occasionally asks questions • Uses search engines like Google to find easily available information of questionable reliability/ appropriateness	• Takes whatever is left for inquiry • Rarely, if ever asks questions • Fails to recognize limits of understanding/ knowledge • Fails to assess the reliability or appropriateness of sources • Demonstrates unsystematic search strategies
KNOWLEDGE BUILDING	• Thoroughly digests findings and communicates effectively to self and others • Consistently identifies deep principles for organizing knowledge as evidenced in research notebook • Constructs an extensive and thorough knowledge base in all problem aspects • Continually asks probing questions	• Digest findings and communicates to self and others • Identifies deep principles for organizing knowledge • Constructs a thorough knowledge base in most problem aspects • Asks probing questions	• Reads inquiry results to group without thorough understanding of material • Learns own area of inquiry but not those of others • Occasionally asks questions	• Fails to understand or be able to communicate inquiry findingsRarely if ever asks questions • Fails to use the problem to develop/enhance BME knowledge
PROBLEM SOLVING	• Repeatedly explores the problem statement to identify critical features • Defines/redefines the problem and identifies problem goals • Breaks problem down into appropriate parts • Identifies and defines appropriate criteria • Frequently uses white boards to assist in problem solving • Consistently applies inquiry results to problem • Develops models and hypotheses	• Explores the problem statement to identify critical features • Seeks to understand problem goals • Identifies criteria • Uses inquiry in problem solving • Uses white boards to assist in problem-solving • Occasionally develops models/ hypotheses	• Relies on group to identify critical features • Lets group identify problem goals and then follows along • Sometimes applies inquiry to problem solving	• Fails to define problem • Articulates no problem goals • Never uses the white boards • Fails to apply inquiry to problem • Never suggests a plan of attack • Fails to develop analytic framework
TEAM SKILLS	• Actively helps group develop team skills • Willingly foregoes personal goals for group goals • Always avoids contributing excessive or irrelevant information • Consistently expresses disappointment or disagreement directly • Consistently gives emotional support to others • Clearly demonstrates enthusiasm and involvement • Monitors group progress and facilitates interaction with other members • Always completes on time	• Supports group goals • Avoids contributing irrelevant information • Expresses disagreement directly • Gives emotional support to others • Demonstrates enthusiasm and involvement • Facilitates interaction with other members • Completes tasks on time	• Goes along with the group • Follows but does not lead • Avoids confrontation even when angry or frustrate • Engages in limited interaction with other members • Occasionally comes unprepared with no explanation	• Does not help in developing team skills • Gives no emotional or intellectual support to team • Lets group down by failing to complete tasks • Observes silently contributing little to process • Shows little or no enthusiasm or involvement

The adopted PDL model retained the main structure developed and tested GT including the following 4 elements:

1. Building the course around three authentic, ill-structured, ill-posed and constrained complex problems with multiple possible routes to multiple possible solutions, emulating real-world engineering.
2. Providing varied but unscripted opportunities for students to identify and document personal knowledge gaps as starting points for individual inquiry and learning.
3. Forming multidisciplinary teams to define, formulate, analyze and collaboratively solve the complex problems, emulating real-world engineering environments.
4. Providing a facilitator (not an expert or director) who guides the learning on a team through asking probing questions that model expert cognitive reasoning and problem solving strategies.

The adopted PDL model was modified by incorporating the following new 6 elements for effective cross-cultural transfer:

1. Designing problems with topics that incorporate cultural relevance and are culturally sensitive both in terms of motivation and constraints.
2. Adopting a skill-based approach to promote metacognitive learning that is of particular importance yet nonstandard to culture.
3. Using cultural-specific assessment well aligned with cultural values and constraints
4. Modifying the role of the facilitator to allow for smooth and gradual transition from teacher-centered to student-centered environment.
5. Managing the team formation and dynamics to allow for gradual transition from structure to choice.

These new elements are described here in detail using BMED 101 at Khalifa University as the case study.

1. Designing problems with topics that incorporate cultural relevance and are culturally sensitive both in terms of motivation and constraints

In the BME course case study, the problem topics were carefully selected based on cultural and societal relevance, emphasizing current health challenges in Abu Dhabi and the UAE. For example, as mentioned above, a typical core problem used at GT for the first problem is the identification of optimal methods for disease screening. In alignment with GT, this problem was selected due to the large amount of inquiry involved towards the solution ranging from the disease mechanisms at the molecular level, to the physics behind imaging technologies, to the protocols involved in a various screening, to the highly experimental research that has the potential to create new screening paradigms [10].

At KU, fresh skins were affixed to the core such that a cultural relevance and benefits were clearly established. For example the following two health challenges were selected at KU for problem one:

- Diabetes mellitus type 2: The United Arab Emirates has the second highest rate of type 2 diabetes prevalence in the world (19.6%), projected to increase to 63% by the year 2030.
- Obesity: The UAE has one of the world's highest rates in over weight and obesity (71% of men and women being either over weight (34%) or obese (36%)).

On the other hand topics such as HIV, drug abuse, female health, or life support were avoided due to cultural constraints. The students responded negatively to these topics and struggled while discussing them, particularly in multi gender teams, hence reducing the learning gains.

The main objective of the second core problem, which is typically related to investigating the accuracy of a particular (medical) device, lies in the design of an experiment meant to test a hypothesis. The team has to use the literature to develop a testable hypothesis. Then they need to develop an experimental protocol for collecting data to either verify or disprove their hypothesis. They must also design and set up an experiment so as to determine whether the results are statistically significant or not. Further, they need to determine what an appropriate sample size will be to achieve significance. And finally every team member has to individually become IRB certified and the group must get IRB approval beforehand (Newstetter et al., 2010). An example of a skin affixed to such a problem at KU based on cultural relevance is *The Design and testing of an Intelligent Speed Control System.* Relevance is immediately established when the text of the problem states that Abu Dhabi has one of the highest rates of road deaths in the world amounting to an alarming 27.4 of 100,000 people, as compared to 15.2 in the US and 11.9 in the EU.

2. Adopting a skill-based approach to promote metacognitive learning that is of particular importance yet nonstandard to culture

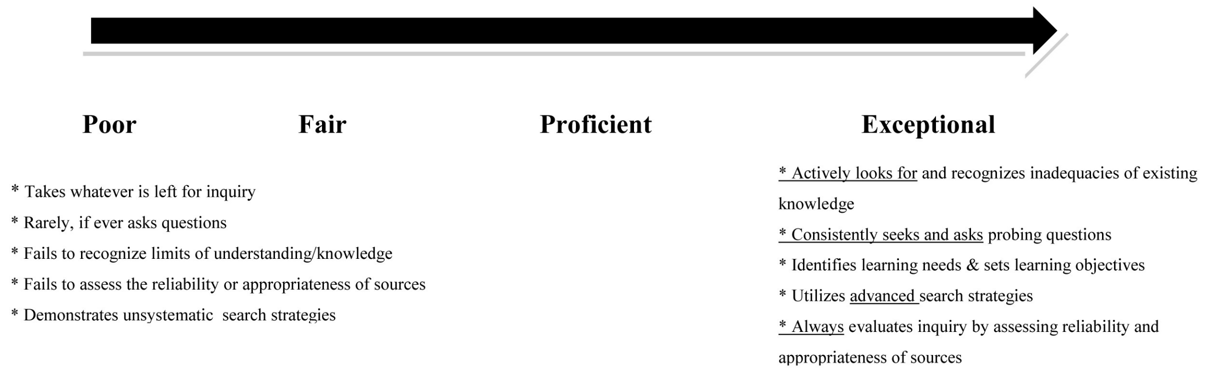
In addition to the skill deficiencies that engineering students suffer from on a global level (see introduction), students in a particular culture may require promotion/validation of certain skills, equally important for the modern engineer, yet lacking in that culture. One example is the ability for different genders to work and communicate effectively in teams. The majority of the students come from one-gender schools, and aside from their relatives they do not interact socially with members of the opposite sex. The PDL course for BME students is one of the first experiences in co-ed education and cross gender professional engagement, and hence provides an opportunity to promote team and communication skills in a co-ed environment. Another important skill that was particularly reinforced at KU is "learning to learn" or autonomous self-directed learning. Inherent to PDL, this skill is critical yet non-standard to a culture that mostly adheres to passive learning didactic lecture models and in which many students, particularly females, are the first generation in their family to attend college. Student teams were empowered to assume initiative and responsibility for their learning and were engaged in the selection, management and assessment of their learning activities. The main goal is to train life-long learners and independent thinkers equipped to undertake a leading role in a future knowledge-based economy.

It is noteworthy to add here that the definition/identification and quantification of learning outcomes and skills is critical. While western students may have encountered some of the aforementioned skills in their previous educational experiences and are able to understand their relevance, the majority of KU students have never heard of these skills or their value. It is therefore essential to engage the students early on in an objective skill-based self-assessment process. For instance, using inquiry skills as an example, the student needs to fully understand and be able to objectively quantify how he/she can move from poor to excellent on that skill line using precise actions that define the various levels (Fig. 2).

3. Using cultural-specific assessment well aligned with cultural values and constraints

As previously mentioned, assessment in the PDL classes at GT targets four specific areas: self- directed inquiry, knowledge building, collaboration skills and problem solving strategies (Table 1). Various alternative assessment methods are used cumulatively at GT towards assessing these skills through the semester. These include inquiry updates, post-problem self and peer evaluations, concept maps, written and oral presentations, and written assessment. While all of these are useful tools to monitor and assess the four target areas, cultural constraints may again play a role in the success and value of these assessment tools. For example, the concepts for peer and self-assessment at KU proved quite challenging, as specific cultural values resulted in systematic underestimation of the students of their own performance and overestimation of that of their peers. The solution (affixed skin) was to share the assessment rubric with the students and have them quantify each of the categories by developing "skill lines" as an instrument to gauge their progress and that of their peers (Fig. 2). The students were hence engaged in the skill assessment and quantification throughout the problem cycle for each of the three problems in a quantitative manner that helped them overcome the cultural assessment constraint. This engagement helped them learn to calibrate and objectively gauge skills (both self and team members).

Alternative assessment methods that were specifically designed for the KU model aside from the skill line instrument shown in Fig. 2, included outside evaluation by a team of experts and content analysis/rubrics of problem/project. Both methods constituted traditional elements that conform with the culture and with which the students were more comfortable as compared to "alien to culture" methods such as self or peer-assessment. In order to provide comfort zones and yet innovate towards self-directed learning, assessment involved a variety of mix and match tools that included various methods (inquiry updates, post-problem self and peer evaluations, concept maps, written and oral



* Takes whatever is left for inquiry
* Rarely, if ever asks questions
* Fails to recognize limits of understanding/knowledge
* Fails to assess the reliability or appropriateness of sources
* Demonstrates unsystematic search strategies

* Actively looks for and recognizes inadequacies of existing knowledge
* Consistently seeks and asks probing questions
* Identifies learning needs & sets learning objectives
* Utilizes advanced search strategies
* Always evaluates inquiry by assessing reliability and appropriateness of sources

Fig. 2. Skill Line for the Quantification of Inquiry Skills.

presentations, and written assessment, and expert evaluations). The main challenge was to gradually progress from grade obsession, a frequent issue with Middle Eastern students, to the focus on learning process and the quality of work. This was partly done assessing the students in some of the work components on the objectivity of their self and peer assessments vs. the work done and emphasizing throughout that the goal is the progress in the skill development (quantified on the skill line, custom made individually for each student), rather than the skill itself or the final problem solution.

4. Modifying the role of the facilitator to allow for smooth and gradual transition from teacher-centered to student-centered environment

The facilitator at GT plays a role that is completely different from an instructor. As previously mentioned, she/he does not give information (act as an expert) or direct the group towards a solution (determine and guide a solution). Instead, the facilitator asks probing questions at the process level with towards explicitly revealing group behaviors by drawing attention to student actions [10]. This approach had to be modified at KU. The majority of the students take this class during their freshman year in Biomedical Engineering. Their high school experience is highly teacher—centered with minimal inquiry—based instruction. The significant change in mode to student-centered learning environment may be counterproductive unless administered gradually and managed properly. Therefore, a vital element in the success of the PDL transfer during the case study required a gradual transition from expert and guide to facilitator. The key was providing the students with the needed expertise or guiding them towards discovering them such as ensuring the availability of these experts (for example a data base on available physicians, health care personnel, health regulation agencies, device industries etc., online tutorials on IRB process, MATLAB, focused tutoring sessions or lectures from experts including professors and physicians, etc.), and implicitly empowering and encouraging them to gradually assume self-guidance as they progress from the first to the last problem during which they the facilitator assumes their pure facilitative probing role.

5. Managing the team formation and dynamics to allow for gradual transition from structure to choice

Team formation at GT was is mostly random. Students are randomly assigned to groups at the beginning of the semester with modification in those groups only if necessary. Student demographics at KU are completely different from the US model. While approximately one-third women, approximately 80% of students are Emirati nationals and culturally are not accustomed to working in mixed-gender groups outside of the family as mentioned above. For most of them, KU is the first place where they have to sit alongside students of the opposite gender since age 10. Furthermore, KU policy states that no student can be forced to work in a mixed-gender situation if they have a conscientious objection to doing so. In addition to the gender complication, the majority of the student population is English Language Learners (ELLs). Since English is the language of instruction, this places further cognitive burdens on students when tackling learning tasks [13]. Gender and language challenges among others have been found to influence self-team formation. Students were observed to cluster together based on comfort level rather than skill or mutual benefit. Students also tended to stick to their own nationality (Emiratis together and non Nationals together). The skin used here to counter balance these challenges is to implement self-teaming in a gradual process. The students are initially teamed in balanced manner consistent with collaborative learning research and in a manner that enhances optimal learning (problem 1). They are gradually empowered to redesign their teams for problem 2 with close supervision by the facilitator and exposure to literature and lectures on effective team formation and the value of diversity in teams. Finally, they are randomly teamed for problem 3 using a computer code that they see on the screen mixing up all their data (gender, nationality, GPA, etc.) and randomly forming a group, hence compelling them to adapt to a typical real-world engineering scenario.

4. Course assessment and evaluation

The implementation of innovative educational pedagogies, such as PDL, often poses a challenge on educators in terms of assessment and evaluation. Not only do educators need to evaluate the particular pedagogy's effectiveness in comparison with traditional techniques, but they also need to assess that the students have met the learning objectives. Since the main objective of the PDL course described here was to develop, nurture and measure student skills in the four categories described in Table 1 (inquiry skills, knowledge building skills, problem solving skills, and team skills), various assessment methods adopted from GT were implemented throughout the process in order to ensure the achievement of the learning goals [11–12]. These included inquiry notebooks, post problem self and peer evaluation using the skill line, concept maps, written and oral presentations, midterm and final facilitator meetings and final written assessment. In the process of the cultural transfer of the course, the self and peer evaluation proved to be the most alien and challenging for the students. As mentioned above, this was addressed by developing graphical "skill lines" (Fig. 2) and detailed assessment rubrics that were shared with the students. The students needed to understand the specific attributes associated with quantifying the skills in order to use the rubric and skill lines objectively. They were rewarded for objective assessment and encouraged to use the "skill lines" as an instrument to gauge their progress and that of their peers.

In the process of evaluating the effectiveness of the course and the cultural transfer, the following instruments were used:

1. Assessment standards adopted from the National Science Foundation Education Standards and handbook (NSF Handbook for Project Evaluation: Science, Mathematics, Engineering and Technology Education [32]).
2. PDL Survey developed in conjunction with Georgia Tech (provided in the Appendix).
3. Student and facilitator interviews during freshman year after taking the class and student exit interviews senior year after graduation.

The particular NSF standards adopted for evaluating the course included the authenticity of the problems presented, providing the students the opportunity to evaluate and reflect on their own learning, and providing means of reporting on student progress. The authenticity of the problems was ensured by adopting original authentic ill-posed and structured problems from GT and adding cultural and societal relevance as appropriate (see the previous section). The modified problems were further verified by the GT team to ensure that the authenticity has not been compromised through the cultural adaptation and transfer. The skill lines, which were custom made in the process of the PDL cultural transfer guaranteed the second NSF standard as the students were given ample opportunity to quantify, assess and reflect on their own learning. Finally, the student progress was both documented and reported through the multiple assessment tools used including the interviews and final assessment.

The PDL survey developed with GT was administered to the students at the end of each semester as well as during the exit interview (Appendix). The students reported on the improvement of skills in the four categories of interest ((inquiry skills, knowledge building skills, problem solving skills, and team skills) as well as the value of collaborative team work, student empowerment and the use of ill-structured, ill-constrained culturally relevant problems to the learning process. The preliminary data using three cohorts of students during three consecutive years (n = 43) showed that in all three cohorts the majority of the students (88%) strongly agreed or agreed that the PDL course enhanced their inquiry skills, the majority (75%) strongly agreed or agreed that the course enhanced their knowledge building skills, the majority (72%) strongly agreed or agreed that the course enhanced their problem solving skills and 98% strongly agreed or agreed that the course enhanced their teaming skills.

The interviews conducted with the students both after the completion of the course and during their exit interviews immediately before graduation confirmed the successful attainment of the learning outcomes. Comments such as "after taking BMED 101, I started evaluating my problem solving abilities using the rubric in all my engineering classes. It made me a much more effective learner". Another student stated that "I owe my excellent presentation skills to BMED 101".

While the preliminary results in this study (mainly qualitative student and faculty interviews, student evaluations and course assessment discussed here) indicate successful cross cultural pedagogy transfer, this work is limited by the lack of sufficient quantitative data that measures and quantifies student learning outcomes of engaging in open-ended complex problem solving. It is also limited by the lack of data that compares the learning outcomes of this course with those obtained in traditional learning settings. Ongoing and future work include the translation of the global 21st century engineering competencies into quantitative measures and standardized performance rubrics that can be turned into authentic performance assessment strategies. This effort remains a challenge and constitutes a much needed focus area in the research of global engineering education. Such rubrics would enable more objective assessment of the efficacy of various implemented pedagogies and of any cross-cultural transfer. The testing of our model on other programs at KU and/or other local universities would provide further means for assessing and improving the current model.

5. Conclusions

This work presented a preliminary model of an exportable system for effective learning pedagogy transfer across cultures using a Biomedical Engineering course at Khalifa University in Abu Dhabi as a case study. The adopted PDL model used in this study is in fact a problem based pedagogical approach in which the labeling was changed from "problem-based" to problem-driven" to emphasize the role of the authentic complex problems in initiating and driving the model. Our main hypothesis is that although globalization in educational reform may be of paramount value, it should not postulate standard or uniform process and outcomes. In other words, cross-cultural transfer of learning pedagogies is valuable to educational reform in developing countries as long as it is accomplished in a culturally sensitive and favorable manner. The model is based on leveraging a mature, well-established, developed, and tested learning pedagogy (here it is PDL imported from our partner institution, Georgia Institute of technology in the United States) as a building block for constructing a culturally sensitive and relevant pedagogical model. The system is based on adopting the main framework inherent to the success of a particular pedagogy, while integrating all the necessary cultural and contextual elements to ensure its applicability and efficacy. For example in the case of PDL, this entails building the "generic core" of the course around authentic, ill-structured complex problems with multiple possible routes to multiple possible solutions emulating real-world engineering; providing varied but unscripted opportunities for students to identify personal knowledge gaps as starting points for individual inquiry and learning; forming multidisciplinary teams to define, formulate, analyze and collaboratively solve the complex problems emulating real-world engineering environments; and providing a facilitator who guides the learning on a team through asking probing questions that model expert cognitive reasoning and problem solving strategies. On the other hand, the smooth and effective cross cultural transfer is accomplished via affixing "cultural skins" to the generic core by using culturally inspired and relevant authentic problems to motivate and promote inquiry-based skills and thinking; skill-based focus to promote metacognitive learning that is of particular importance yet nonstandard to culture; cultural-specific assessment that is effective within cultural values and constraints; appropriate pace transition to student-centered environment (this element may vary significantly between cultures); and culturally sensitive team formation as appropriate. It is noteworthy to add here that the engagement of the experts who have participated in the development and implementation of the original pedagogy at GT in the globalization of the model at KU was proven highly advantageous in our case study. While this may notÂbe always feasible, it sheds the light on the value of diverse, multinational, educational expert teams towards global engineering education reform, particularly with the recent advent of flipped classrooms and MOOCS (massive open online courses).

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Terminology

Scaffolding: Providing sufficient support for students to operate at a higher level than otherwise possible. This typically includes facilitators' help (in the role of a coach or trademaster), score sheets, rubrics, and writing guidelines.

Skin: The storyline of the problem to frame it in a cultural/societal context as necessary.

Metacognetition: Learners' awareness of their own knowledge and their ability to understand, control, and manipulate their own cognitive processes.

Appendix

PDL Survey Questions

1. The PDL class has generally helped me improve my inquiry and learning skills

Strongly agree
Agree
Undecided
Disagree

2. The PDL class improved my knowledge building skills

Strongly agree
Agree
Undecided
Disagree

3. The PDL class improved my problem solving and critical thinking skills

Strongly agree
Agree
Undecided
Disagree

4. The PDL class improved my team and group dynamics skills

Strongly agree
Agree
Undecided
Disagree

5. The PDL class has helped me gauge and quantify my inquiry, knowledge building, problem solving, and team skills based on the assessment rubric

Strongly agree
Agree
Undecided
Disagree

6. I found collaborative work in teams to encourage a stimulating learning environment

Strongly agree
Agree
Undecided
Disagree

7. I found the PBL style of introducing complex, ill-constrained, ill-structured, authentic problems motivational for learning

Strongly agree
Agree
Undecided
Disagree

8. I found the empowerment of students to self-learn and the ownership of the learning process motivational for learning.

Strongly agree
Agree
Undecided
Disagree

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Wendy C. Newstetter's research focuses on understanding cognition and learning in interdisciplines with an eye towards designing educational environments that support the development of integrative thinking and problem solving. Towards that end, she uses ethnographic methods to study in-vivo learning and problem solving in research laboratories—tissue engineering, neuroengineering and biorobotics—where the nature of the problems demands multidisciplinary teams with complementary skills and knowledge. Newstetter uses this research to then inform the design of problem-based learning (PBL) classrooms designed to support the development of integrative knowledge building and reasoning strategies. Most recently, she has been working to develop PBL models for instructional laboratories where students use techniques learned to tackle student-generated problems on the bench top. Newstetter also works with faculty both at Georgia Tech and throughout the nation through Project Kaleidoscope to develop more effective science, math, and engineering educational environments informed by learning and cognitive science research.