DRAFT: COMPETENCIES FOR INNOVATING IN THE 21ST CENTURY

Zahed Siddique¹, Jitesh Panchal², Dirk Schaefer³, Sammy Haroon⁴, Janet K. Allen⁵ and Farrokh Mistree⁵

¹The School of Aerospace and Mechanical Engineering
University of Oklahoma
Norman, Oklahoma 73019

²The Collective Systems Laboratory
Washington State University
Pullman, Washington 99164

³The Systems Realization Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

⁴The RBR Group
Chapel Hill, NC 27516

⁵The Systems Realization Laboratory @ OU
University of Oklahoma
Norman, Oklahoma 73019

ABSTRACT

This is the first paper in a four-part series focused on a competency-based approach for personalized education in a group setting. In this paper, we focus on identifying the competencies and meta-competencies required for the 21st century engineers. In the second paper, we provide an overview of an approach to developing competencies needed for the fast changing world and allowing the students to be in charge of their own learning [52]. The approach fosters “learning how to learn” in a collaborative environment. We believe that two of the core competencies required for success in the dynamically changing workplace are the abilities to identify and manage dilemmas. In the third paper, we discuss our approach for helping students learn how to identify dilemmas in the context of an energy policy design problem [64]. The fourth paper is focused on approaches to developing the competency to manage dilemmas associated with the realization of complex, sustainable, socio-techno-eco systems [65].

A deep understanding of innovation-related competencies will be required if we are to meet the needs of our graduates in preparing them for the challenges of the 21st century. In recent years development of competencies for innovation, especially in engineering, has received signification attention. The nature of innovation and its components needs to be identified and analyzed to determine proper ways to nurture and develop them in engineering students.

There are two levels of competencies in any professional field, field-specific task competencies, and generalized skill sets, or meta-competencies. The task-specific competencies are benchmarks for graduates in a given field. Their level of attainment defines how well graduates are prepared to meet job demands and excel in the future. The general (meta) competencies are skill sets that enable them to function more globally, such as to work with others, function in organizations and meet organizational demands, and transfer task-specific skills to new challenges they have not encountered before. Hence, in this paper we will explore the key question: How can we foster learning how to learn and develop competencies?

1 FRAME OF REFERENCE

1.1 Innovation – What is it?

The rapid progress of globalization [1] has led to many unprecedented changes in the world in which students are educated and in which graduates will practice. As Friedman [1] puts it, “Globalization has collapsed time and distance and raised the notion that someone anywhere on earth can do your job, more cheaply. Can Americans rise to the challenge on this leveled playing field?” In 2004, the National Academy of Engineering published a report summarizing visions of what the engineering profession might be like in the year 2020, [2]. A follow-up report [3] on how to educate the engineer of 2020 was released a year later. The key message gleaned is that engineering education has to be adapted to the challenges of the future with regard to globalization.

Globalization has put engineering education and the profession in a challenging crossroad [4]. The impacts of rapid technological innovations on the modern societies have been
amplified by the globalization of the economy [1]. The competitiveness of the U.S., which is linked to the standard of living, is dependent on our ability to produce a large number of sufficiently innovative engineers [2,3,6,7]. Serious concerns have been raised about whether the U.S. is adequately preparing the next generation [8] for the demands of an increasingly high-tech and interdisciplinary workplace, and whether enough scientists, engineers, and highly skilled workers are being produced [9-10]. The post-recession world economy is going to be defined by a New Normal - one that may require us to adopt game changing strategies for industry to remain competitive in an interconnected world and for academia to equip engineers with the appropriate competencies.

Innovation and independent problem-solving are marks of domain expertise in applied fields [11]. Experts have defined innovation as “A novel idea, put into practice that offers value to customers and/or society” [12]. Innovation requires both information/knowledge and independent choice to initiate action [13]. Innovation is supported by both cognitive and affective/motivational factors, which, in turn, are informed by learning theory and research [14]. Cognitive characteristics to support expertise development and innovation include depth of domain knowledge and skill, awareness of the situational factors that influence choices, and knowledge of adaptive task characteristics that may transfer to the current challenge [15]. Motivational and affective characteristics that support expertise development and innovation include self-efficacy [16], self-determination [17], and self-regulation [18]. Together they comprise an integrative framework to investigate, understand and promote innovation, learn to learn, and learn to create [13].

1.2 21st Century Dilemma Management to Support Innovation

While there is a broad agreement that engineering education needs to change based on the current dynamics of globalization, innovation-centric value creation, and such, there appears to be little tangible advice rooted in practical experience as to how exactly that change is best to occur. Many educators agree, that one step in the right direction is to anchor engineering education in a more holistic perspective [19-22]. Consequently, the key question is: How can we foster learning how to learn and develop competencies?

There ought to be a better symbiosis of societal needs, technologies, cross-disciplinary integration and associated educational activities. Our task at hand is to prepare engineers who are capable of identifying and solving problems that do not yet exist with tools and methods that have not yet been invented.

“We are currently preparing students for jobs that don’t yet exist using technologies that haven’t been invented in order to solve problems we don’t even know are problems yet”

Former Minister of Education Richard Riley.

“We can’t solve problems using the same kind of thinking we used when we created them” – Albert Einstein.

A new approach to foster innovation is the concept of 21st century dilemma management.

A dilemma (Greek: δί-λημμα "double proposition") is a problem offering at least two solutions or possibilities, of which none is practically acceptable. One in this position has been traditionally described as "being on the horns of a dilemma", neither horn being comfortable, "between Scylla and Charybdis"; or "being between a rock and a hard place", since both objects or metaphorical choices are rough. This is sometimes more colorfully described as "Finding oneself impaled upon the horns of a dilemma", referring to sharp points of a bull’s horns, each of which are equally uncomfortable.


In essence, the big challenge boils down to educating students in the art of learning how to learn and to empower them to take charge of their own education within the context of an ever-increasing amount of subject matter to be comprehended. We believe that the competitiveness of the next generation of engineers in general will no longer be defined solely by their knowledge and technical skills but also by their abilities to identify white spaces and then proffer solutions that address the dilemma of improving the quality of life without adversely affecting the environment.

White space discovery occurs through Dilemma Management. It occurs when the engineering reductionist approach to continuously bounding a problem to drive out a solution is reversed to gain perspective, at times leading to breakthrough solutions. The engineer is able to build upon the existing learning while educating self through the inquisition or removal of problem boundaries. The engineer receives a broader perspective offering a greater understanding of three specific constructs for Dilemma Management are (for both upstream and downstream of the problem): engineered solutions, their impact on economics and quality of life.

Dilemma Management approach broadens the purview of the problem, whilst the engineer begins to see a set of “events” rather leading to the problem being worked on. For example, the engineer may discover that the problem ceases to exist if an upstream event is managed, eliminating the problem completely. Such activities enable the engineer to create new knowledge, and develop competencies to collaborate in a flattened world across multi-disciplinary and multi-cultural backgrounds. Managed Dilemma’s are key to delivering transformations in the three constructs mentioned above.
A key differentiator of leaders and followers will be their ability to create their own knowledge and constantly improve and update their competencies in an ever changing world. Hence, they need to be provided an opportunity to learn how to learn. We believe that, in light of the preceding, engineering education should be augmented with students learning how to create and implement ‘game changing’ strategies to better prepare students for the world of near tomorrow, in which distributed value creation in an interconnected world will be the new normal [23,24].

1.3 Interconnected and Wired World

The world of technology is becoming increasingly complex and dynamic. The skills that were considered valuable yesterday are becoming the commodities of today and tomorrow [1, 25]. Realizing how much the world has changed over the past twenty years, it becomes apparent that this change needs to be better reflected in the way engineering designers are educated [2,26,27]. Complex social networks, consisting of millions of individuals, have formed over the Internet through emerging Web 2.0 technologies such as blogs, discussion boards, wikis, and collaboration networks such as Facebook, video networks such as YouTube, and countless others. Information is readily available to everyone through the Web, anytime and anywhere. Individuals, who have never met physically, i.e., in person, are already collaborating on the development of complex products and services for major companies, solving challenging problems that are openly ‘crowd sourced’ to the community of interested engineers and scientists. For the next generation of engineers, this new paradigm will be the new norm. Their number one material to work with will be information, their final product(s) will be intellectual property and innovation, and their generation is becoming known as the generation of knowledge workers.

Over the past two decades web-based technologies have brought about revolutionary changes in the way organizations conduct business. Organizations are increasingly transforming into decentralized supply and demand networks. According to Friedman [1], we have now reached the era of Globalization 3 (G3), in which individuals have the power to collaborate and compete globally. Globalization 3 has led to the emergence of various new paradigms related to breakthrough innovation that are characterized by the self-organization of individuals into loose networks of peers to produce goods and services in a very tangible and ongoing way. Examples of such paradigms include mass collaboration [28], collective innovation [29], collective invention [30], user innovation [31], crowd sourcing [32], open innovation [32], and community-based innovation [34].

New organizational structures based on self-organizing communities are emerging to complement traditional hierarchies. According to Tapscott and Williams [28], the new principles for success in G3 are a) openness to external ideas, b) individuals as peers, c) sharing of intellectual property, and d) global action. In such emerging organizations, individual success is defined by the recognition gained through contributions towards a common goal rather than by following the directions from the top management. An organization's success is determined by its ability to integrate talents of dispersed individuals and other organizations. Hence, the skills and competencies required for success in the G3 world vary from the ones required for success in the Globalization 1 or Globalization 2 eras.

In addition to this, the overall workplace characteristics of the near future are expected to be very different from the current ones. According to Meister and Willyerd [35], by the year 2020:

- The workplace will be highly personalized and social.
- Employers will need to adjust to the unprecedented challenge of having up to five generations of individuals working together.
- Employers can expect to manage employees with vastly different interests and life experiences from varied regional, ethnic, and cultural backgrounds.
- Employers must provide fully individualized benefits and services.
- Traditional offices and nine-to-five work schedules will be largely passé.
- Knowledge workers will dominate. Lifelong learning will be the rule.
- Employees will expect and demand robust internal and external online connections.
- The future HR staff will include positions that do not yet exist, such as ‘talent developing agent’.

Similarly, Benko and Weisberg [36] describe an ongoing shift away from the traditional career ladder model to a career lattice. That is, a model to allow for customized and flexible career paths based on new organizational forms that better fit the workforce of near tomorrow. In summary, for our graduates to succeed in the world of near tomorrow, we must provide an opportunity for them to learn and play in a whole new game of design and engineering.

In the next section we present a review of competencies for innovation. These competencies are used to support innovation in an interconnected world (Section 3).

2 APPROACH

In order to answer the key question posed at the beginning of this paper,

How can we foster learning how to learn and develop competencies?

we need to identify and understand the nature of competencies and meta-competencies needed to support innovation in the 21st century. In addition, we present a brief overview of an approach to instructional design to develop courses that support innovation.
2.1 Review of Competencies and Meta-competencies

Corporations and employers have frequently pointed to a lack of professional awareness and low levels of communication and teamwork skills in engineering graduates [37-40]. These issues have led the U.S. Accreditation Board for Engineering and Technology (ABET) [41] to transform their accreditation criteria from a content-based approach to an outcomes-based approach. ABET now proposes to hold engineering schools accountable for the knowledge, skills, and professional values engineering students acquire (or fail to acquire) in the course of their education. Consistently engaging in higher level cognitive activities and achieving the higher level objectives of analysis, synthesis, and evaluation involve more than following a new set of procedures. We do not want merely to adopt a cycle or set of external procedures to follow. We want our learners to develop higher order habits of mind.

There are two levels of competencies in any professional field, field-specific task competencies, and generalized skill sets, or meta-competencies. The task-specific competencies are benchmarks for graduates in a given field, and their level of attainment defines how well-prepared they are to meet job demands and excel in the future [42,43]. The general (meta) competencies are skill sets that enable them to function globally, such as to work with others, function in systems and meet organizational demands, and transfer task-specific skills to new challenges or tasks they have not encountered before [44,45]. Thus, our goal is to revolutionize our learning community to develop an intentional culture of reflection, wherein members (both students and faculty) develop dispositions of metacognition and self-regulation.

The nature of innovation is changing. A large body of evidence suggests that raw production of ideas alone is no longer sufficient for accomplishing innovation. The problems that we are facing today are global and complex in nature, where engineers need to manage dilemmas among economic, social, ecological, and intellectual capital. Specifically, future innovations will increasingly originate from teams of collaborators who can bring together multiple skills and perspectives. The competencies required by future engineers will have to support innovations that go beyond the current models of only economic capital. The innovators of the future will need to be equipped with more than just specialization skills [46]. Future engineers need to have “Global” competencies to address issues that go beyond local context [46-48]. Global competence has been defined as “knowledge, ability, and predisposition to work effectively with people who define problems different than they do” [49]. From literature, Warnick [47] identifies eight categories of Global competence for engineers: exhibit a global mindset; appreciate and understand different cultures; demonstrate world and local knowledge; communicate cross-culturally; understand international business, law, and technical elements; understand international business, law, and technical elements; live and work in a transnational engineering environment; and work in international teams.

The development of competencies to support engineering, in general, and innovation in particular, is spiral in nature, with students building on some and adding new ones as they progress through the curriculum. In this paper we focus on the development of meta-competencies to support innovation, with the understanding that technical competencies in domains are a pre-requisite to negotiate dilemmas. We build on a set of meta-competencies compiled by various educators and researchers [43,45], to generate a list of meta-competencies that need to be developed by future engineers to support innovation.

**Ability to Manage Information**
- Ability to gather, interpret, validate and use information
- Understand quantitative and qualitative information
- Discard useless information

**Ability to Manage Thinking**
- Ability to identify and manage dilemmas associated with the realization of complex, sustainable, socio-techno-eco systems
- Ability to think across disciplines
- Holistic thinking
- Conceptual Thinking
- Ability to speculate and to identify research topics worthy of investigation
- Divergent and convergent thinking
- Ability to engage in critical discussion
- Identify and explore opportunities for developing breakthrough products, systems or services
- Ability to think strategically through theory and methods

**Manage Collaboration**
- Ability to manage the collaboration process in local and global settings
- Ability to create new knowledge collaboratively in a diverse team
- Negotiating competence
- Teamwork competence

**Manage Learning**
- Ability to identify the competencies and meta-competencies you need to develop to be successful at creating value in a culturally diverse, distributed engineering world
- Ability to self-instruct and self-monitor learning
- Ability to interact with multiple modes of learning

**Manage Attitude**
- Ability to self-motivate
- Ability to cope with chaos
• Ability to identify and acknowledge mistakes and unproductive paths;
• Ability to assess and manage risk taking

In the context of an innovation economy, critical thinking provides the foundation for developing meta-competencies. These competencies and meta-competencies need to be developed at Level 6 of Bloom’s Taxonomy.

2.2 Review of Instructional Design of Courses that Support Innovation

Course or curriculum redesign must address “what” is to be learned, and “why” those target outcomes are needed. Then, building on those goals, it should present clearly the “how” or strategies used to achieve them. In this case, the “what” and “why” refer to the highest level of educational objectives in Bloom’s (revised) taxonomy [50]. We know that current engineering students will be tomorrow’s engineering experts and that they will have to face and address challenges that are very different from the problems and tasks they were exposed to as students. The nature of those challenges will require them to take on open-ended problems and unforeseen issues, understand system level challenges, address them with creative thinking, and respond to them with innovations. To be successful at creative level of Bloom’s Taxonomy, learners also must succeed at the two preceding levels, analyzing the relevant issues, requisite resources, and demands of the task to be achieved, then evaluating the potential responses and choosing among available options to produce the most effective and efficient solution/response. Thus, to be prepared to innovate, engineering students must be able to perform at the top levels (Evaluating and Creating) of Bloom’s taxonomy [50]. If they have not experienced creative challenges that require innovative responses in their engineering classes, they will not be prepared to do so in their professional careers.

The “how” of developing this type of skill and expertise in analysis, evaluation, and creative production for unforeseen needs requires authentic experience in tasks that require students to exercise these skills. There are various ways to provide practice in creative problem-solving and innovation. One way that not only provides the experience, but also leverages a number of other advantages for developing these skills, is experiential learning. If designed well, experiential learning not only provides authentic opportunity, but also supports self-determined motivation and regulation. Further, it can be structured to enable adaptive interaction among those with various types of expertise, sharing in a professional community, and building both competence and community. However, most of what is presented as “creative problem-solving” or “experiential learning” in education (engineering and across disciplines) is far more structured than is required to develop these ways of thinking. Most instructors create tidy textbook problems with perfect model answers, not realistic tasks that require real innovation to be solved. Solving neat, well-defined problems only gives learners practice in solving those, not in creativity and innovation. To learn to respond to open-ended problems or tasks without existing solutions, learners need to engage in practice with exactly those types of tasks.

Beyond the task itself, there are elements in the learning environment that promote learners seeking a predetermined “right” answer. These are communicated in grading models, teacher style and communication, and role modeling. An additional layer of challenge in redesigning tasks and models for classroom use is in re-educating faculty to support authentic experiential learning. This involves balancing structure and autonomy, supporting both team and individual effort, and valuing error that leads to deeper learning and skill refinement. Related to these outcomes is the power of metacognition, reflection on task process and products, both during and after experiences. This productive metacognitive reflection is one of the most powerful elements of expertise development. It is directly linked to the process skills of analysis and evaluation and, within a discipline, divides legitimate creative experts from those whose skills are limited to doing the same thing, albeit doing it well, over and over again [15].

3 OUR EDUCATIONAL APPROACH TO SUPPORT INNOVATION IN AN INTERCONNECTED WORLD

3.1 The Course Setting

We have created an approach for helping students attain competencies and meta-competencies required to succeed in the world of near tomorrow. The approach has been implemented in graduate level design courses. It involves a fundamentally different way in which design-related courses are orchestrated. Some of the unique aspects of our approach are as follows.

First, instead of delving right into the subject matter of engineering design, students are asked to speculate about the world of design and manufacturing of the year 2030, based on current literature and developments, before learning about the engineering design process as we know it. By speculating about the world of 2030 they get a new perspective on the potential requirements of future engineering design processes. Thus, students create new knowledge beyond what they could learn from any given text book.

Second, the students are required to take stock of their current competencies and compare what they already have to the competencies a successful designer may need in future. Thereby, students are empowered to take charge of their own learning by articulating their individual associated learning objectives within the broader context of this course.

Third, we provide a single question to be answered throughout the semester. At first, most students do not believe that the Question for the Semester they are presented in the first lecture of the semester indeed is their take-home exam and that they even have the right to tweak this question in response to their personal learning objectives. That way, they are encouraged to start shaping their own learning.
Fourth, students are strategically guided to form a learning organization of self-organizing individuals that, collectively, leverage each other’s competencies to solve a common problem. For about a week, they wait for the orchestrators to tell them exactly what to do to get started with their group project. However, we refuse to do so and shortly afterwards a natural response of emerging leadership forms and students start taking on team roles based on their respective competencies and previous experiences.

Our courses are offered to students in a distributed learning context. On-campus students are actually located at different campuses such as Atlanta, Savannah, and Lorraine (France) and in addition to that distance learning students from all over the world participate in these courses as well. Most students take our courses after they have had some introductory engineering design course in which they became familiar with a systematic design approach (such as the one by Pahl and Beitz [51]). To reach all students, synchronous and asynchronous education techniques are incorporated. The lectures are recorded and uploaded to a content management system so that all students can access them online at any time. Besides in-class interactions, the students are encouraged to communicate with the course orchestrators via email, telephone, video conference or the online forum on the course website. Online social networking tools such as Facebook, Wiggio and LinkedIn are used to enable communication between students. To bring the groups of on-campus and distance-learning students closer to each other, we have developed a collaborative learning framework that enables students to interact through a course internal social network.

The framework is based on Web 2.0 technologies such as collaborative wikis, and open source software development principles. Through this web-based framework we provide a variety of tools to support both synchronous and asynchronous communication between the participants. The use of such a framework for collaborative learning also provides students the opportunity to experience the challenges and benefits of emerging mass-collaborative environments (Panchal and Fathianathan 2008). Recently we offered this course jointly across two universities – Washington State University and University of Oklahoma. The details of this course are discussed in the second paper in this series [52].

The content of the courses is based on emerging concepts such as open engineering systems [53], globalization 3.0 [1], and mass collaboration [54]. The students are challenged to determine the requirements for design approaches to work well in the context of the rapidly changing world with its new paradigms of mass collaboration, open-innovation, crowd-sourcing, and the like. Hence, the syllabus also contains topics from economics (e.g., globalization, global markets), business (e.g., value chain, supply chain, outsourcing), law (intellectual property protection), IT (e.g., web 2.0) and social sciences (e.g., social networks, cultural differences, motivation).

3.2 Foundations of the Approach

Our approach is based on the following foundations:

a) Question for the Semester, which is a common thread to tie the components of the course together
b) Mass customization of learning experiences through Assignment 0
c) Definition of competencies anchored in Bloom’s taxonomy
d) Scaffolding of activities
e) Collaborative and Collective learning through a learning organization
f) Reflective practice through Observe-Reflect-Articulate and learning essays
g) End of Semester deliverables for reflection and self-assessment

The details of these foundational constructs are discussed in the following subsections.

3.2.1 Question for the semester to establish context

In personalizing a course, the challenge for the course orchestrators is to keep the students’ efforts aligned with the objectives and topics intended. This is achieved through structured assignments in a predefined form with firm due dates. These submissions are created to challenge the students, arouse their curiosity and let them discover issues related to the course they are personally interested in. This is realized by posing the Question for the Semester (Q4S) and several associated assignments that are scaffolded towards the answer to this question. In the first lecture, the Q4S is presented. It is a take home exam that is due at the end of the semester. The question for the semester is used to align the efforts of all the students while providing enough flexibility to the students to explore the topics that are particularly interesting to them. Examples of the questions for the semester used during different semesters are shown below.

**Question for the Semester – Spring 2008**

Imagine that you are operating a product creation enterprise in the era of Globalization 3.0. Your task is to define your company and develop a business plan. This includes answering the following key questions:

a) How do you envision the world of 2030 in such an environment?
b) How do you see yourself and your company operating in this world of 2030? Please take into account your engineering expertise and your passions.
c) What are the competencies that you would require to be successful in such an environment? Please identify the drivers and metrics for success.
d) What would your strategy for product development be in the world of 2030? What kind of products / processes do you plan to offer? How would you structure your design and manufacturing process? What kind of collaborations with other companies do you envision? What kind of supply chains do you envision your company to be involved in? How would you utilize the intellectual capital available throughout the world?
e) What would the IT framework for collaborative product realization in 2030 look like?
Imagine that you are operating a product creation enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. Your brief is to identify the characteristics of the IT infrastructure to support the technical collaboration that furthers open innovation.

**Question for the Semester – Spring 2011**
Imagine that you are operating a product creation enterprise in the era of Globalization 3.0 where individuals are empowered to participate in the global value network. Your brief is to identify and discuss the characteristics, opportunities and challenges of a Product Development Process (Design and Manufacture) that furthers open innovation and is based on crowdsourcing and mass collaboration.

**Question for the Semester – Fall 2011**
We imagine a future in which individuals are empowered to participate in the global value network where geographically distributed people (including engineers) collaboratively develop, build, and test solutions to complex socio-techno-eco systems.

**Bridging fuel:** What are the technology, policy and communication dilemmas associated with utilizing natural gas as bridging fuel for next 25 years, while minimizing the adverse impact on quality of life?

**Policies for distributed generation technologies:** What are the technology, policy and communication dilemmas associated with implementing the Feed-In-Tariff (FIT) policy while maximizing the adoption of distributed generation technologies?

Every time we use this approach in a course, a similar question with a different focus is posed and serves as a foundation for the entire course. All learning activities are directed towards answering this question. To support the individual interests, the students are allowed to tweak and personalize this question according to their personal learning objectives (see Section 3.2.2). The changes a student is allowed to make to the Q4S are limited and have to be approved by the course orchestrators. In a mass customized course, this framing is particularly important to keep the students focused on their personal objectives. That way, the students can evaluate their work towards the answer of the Q4S and can prioritize their ideas.

### 3.2.2 Mass Customization through Assignment 0

Our first effort at mass customization of educational experiences is published in [55]. As a ramification of the ongoing globalization, the skills that were considered valuable yesterday are becoming the commodities of today and tomorrow [1,56]. Realizing how much the world has changed over the past 10 years, it becomes apparent that this change needs to be better reflected in the way engineers are educated [2,3,26,57]. Some educators have articulated that engineering education needs to be considered from a holistic point of view [19-21]. There should be a better symbiosis of societal needs, emerging technologies, cross-disciplinary domain integration, and aspects related to cultural diversity and ethical issues. Our task at hand is to prepare engineers who are capable of identifying and solving problems that do not yet exist with tools and methods that have not yet been invented. In essence, this boils down to educating students with respect to learning how to learn and to empower them to take charge of their own education. From the perspective of an individual, this translates to identifying and obtaining the competencies needed to become a valuable asset for a dynamic career. Hence, the first step to customize the course is to let the students identify their personal goals for the semester. This is achieved in an assignment (Assignment 0) which is given during the first class. In this assignment, the students’ task is to identify the goals that they want to achieve. These goals are referred to as the personal semester goals. The goals consist of learning objectives and competencies that they want to achieve during the semester. The learning objectives and meta-competencies identified by one of the students are shown in Figure 1 as an example.

Competencies are the result of integrative learning
experiences in which skills, abilities, and knowledge interact to form bundles that have currency in relation to the task for which they are assembled [58]. On the other hand, learning objectives are generic skills that students wish to attain so that they become competent in performing the task. Learning objectives are defined in terms of the six learning domains defined in the Bloom’s taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation). In the examples of learning objectives, the keywords from Bloom’s taxonomy are highlighted.

Having identified the students’ personal goals, the course orchestrators use a scaffolding scheme to design a personalized learning experience in a group setting, thereby mass customizing the course to different student needs. The scaffolding is achieved through the “Question for the Semester” (Q4S) and the various assignments. The assignments are scaffolded and provide opportunity for personalization. This ensures that everybody in the class works in the direction intended by the course orchestrators. The lectures are used to convey core course content and additional aspects that may help students with their assignments and learning essays. While answering the Q4S the students work in a collaborative manner which provides the opportunity to create new knowledge by combining the diverse knowledge in the personalized section of the course.

3.2.3 Competencies anchored in the Bloom’s taxonomy

While there are many other taxonomies of learning we have chosen Bloom’s taxonomy [59] as a framework within which to orchestrate student’s learning. We decided to use Bloom’s traditional taxonomy because, based on our experience, engineering students find natural and easy to grasp. In 1956, Bloom [59] developed a classification of levels of intellectual behavior important in learning. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order, which is classified as evaluation. As alluded to before, these six levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. Traditionally, the first three levels mapped into the undergraduate curriculum and the three upper levels mapped into the graduate curriculum. Lately, this division has been vanishing as educators have realized the importance of addressing all levels of Bloom’s taxonomy from early on in the curriculum.

Bloom’s taxonomy provides a systematic way of describing how a learner’s performance grows in complexity when mastering academic tasks. It can thus be used to define curriculum objectives, which describe where a student should be operating. In addition, Bloom’s taxonomy provides a powerful means to assess students’ performance, justify associated grades, and at the same time provide students with feedback as to how to improve their performance. In a truly constructively aligned curriculum it facilitates deep learning as the activities are designed for that purpose.

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3.2.4 Scaffolding of activities

We facilitate our students learning how to learn through scaffolding. Scaffolding involves four instructional cornerstones: (1) scaffolding; (2) reflective practice; (3) customization; and (4) collaboration. A combination of these utilizes a variety of educational approaches to foster deep learning among students. The scaffolded part frames the content of the course with the Q4S and several associated assignments. The assignments are structured (scaffolded) and provide opportunity for individualization. This ensures that everybody in class works in the direction intended by the course orchestrators. The lectures are used to connect the assignments to the customized components of the course. The lectures are also used to convey core course content and also cover additional aspects that may help students with their assignments. The collective knowledge and experience of the students enrolled in our course is harnessed to create a collective solution to an open ended mass-collaborative design problem and the answer to the Q4S that could not be accomplished by an individual.

3.2.5 Collaborative and Collective Learning through a Learning organization

We facilitate collaborative and cooperative learning in our student learning community. Today, the term collaborative learning stands for a variety of student-centered educational approaches that involve joint intellectual effort by learners and instructors. It refers to educational methodologies and learning environments in which learners engage in common tasks in which each individual depends on and is accountable to each other. Groups of students usually work together in order to understand something, grasp a meaning, or develop a solution to a problem. The theory of collaborative learning is tied together by a number of important assumptions about learners and learning processes. These include (a) that learning is an active, constructive process in which learners create new knowledge by using, integrating and reorganizing their prior knowledge; (b) that learning depends on rich context, which
influences the success of learning significantly; (c) that learners are diverse in terms of background, knowledge, experience and learning styles; and (d) that learning is inherently social, which makes student interaction an important part of education. All of these aspects of learning are supported by the means of collaborative learning where students solve problems and create knowledge in a diverse group setting. The term collaborative learning also refers to a collection of tools, which learners can use to collaborate, assist, or be assisted by others like they are used in e-Learning and distance learning environments. Such tools include virtual classrooms, chat rooms, discussion threads, as well as application and document sharing.

The term collective learning is not uniquely defined and most widely used in the context of vocational education. There is a clear distinction between learning in social interactions (with and from others) and collective learning, where the learners consciously strive for common learning and/or working outcomes. They use the term collective learning for educational systems, in which the intended outcomes (and perhaps, the process of learning), are collective. This is a key point of relevance with regard to the pedagogical approach presented in this paper. The three major forms of collective learning are (a) learning in networks, (b) learning in teams and (c) learning in communities.

According to Panitz [60], collaboration is a philosophy of interaction and personal lifestyle and cooperation is a structure of interaction designed to facilitate the accomplishment of an end product or goal. Cooperative learning [60] is more directive than student-centered collaborative learning and closely controlled by the course orchestrator. Our approach features elements of both philosophies.

We orchestrate the learning of an individual in a group setting through the formation of a learning community in a distributed distance learning setting. The blueprint for this is the model of the Learning Organization (LO) as introduced by Senge in his famous 1990s book ‘The 5th Discipline’ [61]. According to Senge, a Learning Organization is “an organization that facilitates the learning of all its members and consciously transforms itself and its context”. A learning organization exhibits five main characteristics: (1) systems thinking, (2) personal mastery, (3) mental models, (4) a shared vision, and (5) team learning.

An obvious issue with introducing this paradigm of the Learning Organization into the classroom environment is that it was mainly developed for companies, based on the business models and practices of the 1990s. However, our graduate students, future engineers, are required to form such a learning organization within their distributed learning environment. Hence, one of our key activities is to analyze the original model of the LO and augment it to better fit the needs of our educational setting and the characteristics of the G3 world of near tomorrow.

### 3.2.6 Reflective Practice through Observe-Reflect-Articulate and Learning Essays

It is critical that the individuals learn from a collaborative learning experience. In a mass-customized course [55] the articulation of individual learning is crucial since it is the prerequisite for the evaluation of an individual’s progress. Usually students are not used to this and have difficulties with the articulation of their learning. They are used to showing their learning during exams in a strictly predefined way. Here the students require a learning construct that provides guidance through the entire learning process and helps them to identify and express their learning and new knowledge. Therefore, the Observe-Reflect-Articulate (ORA) construct [55] is introduced to the students at the beginning of the semester. It consists of three phases:

1. **Observation**, in which existing knowledge is reviewed from different sources like lecture, literature, magazines or newspapers.
2. **Reflection**, in which the observed knowledge is synthesized by reflecting on given or self discovered questions.
3. **Articulation**, in which learning and new knowledge, gained from the first two phases, is expressed.

By following these steps during the submissions the students internalize the process of learning and deeply learn how to learn. This is one way of introducing students to what in education is referred to as reflective practice, as introduced by Schon [62] Learning essays are encouraged weekly submissions in which students review and explore topics from the lectures in context of their individual semester goals. To direct the students, at the end of each lecture guiding questions are suggested that may help them to better relate the lecture content to the big picture of the course. The students also have the freedom to choose other course-related themes for their learning essays. Since nothing is graded till the end of the semester (we provide formative assessment [63] throughout the semester), the students are more willing to take risks in choosing topics and developing new thoughts in their essays. If the orchestrators realize that a student is on a wrong track they express this in the individual feedback and provide corrective guidance.

A core aspect of the learning essays is that the students apply and internalize the Observe-Reflect-Articulate construct for reflective practice and thus learn how to create new knowledge and enhance their critical thinking skills. At the end of the semester the students reflect on their learning in a Semester Learning Essay by relating it to a non-engineering analogy or metaphor. Examples of metaphors used by the students include football, cooking, golfing and writing poems. Here, the students can show insight and demonstrate that they really proceeded in achieving their semester goals.
3.2.7 End of Semester deliverables for reflection and self-assessment

At the end of the semester, students are called on to close the loop with regard to what each has learned – to what extent each has achieved the competencies and the associated learning objectives proposed in A0 and refined through the semester. The students are required to revisit all their submissions, reflect on the feedback that was provided and take stock of how much each of the learning activities throughout the semester have actually helped them to attain the desired competencies and meet the corresponding learning objectives. To what level of Bloom’s Taxonomy have they managed to climb and to what degree have they learnt how to learn? This process of reflective practice is presented to the students by means of A0-EOS, an extended end-of-semester version of the original Assignment 0.

In addition to revisiting the questions of A0, the students are called on to reflect on their learning process, the quality of their contributions to the various assignments, the value gained with respect to attaining their individual learning objectives and competencies as well as the value added to the overall learning organization. Finally, based upon this self-reflection, the students are asked to propose a grading scheme for evaluating their own work as well as that of their peers. This includes developing a comprehensive assessment rubric showing the categories of work to be assessed along with justifications for the various degrees of achievement, as well as the articulation of the specific grades they believe they have earned.

In summary, the underlying architecture of the course facilitates mass-customization of learning while addressing the technical competencies and meta-competencies required to be successful in an ever changing global work environment. While the course does require significant commitment from the orchestrators, its architecture with a core element and customizable components makes it manageable.

4 CLOSURE

In this paper, we discuss the competencies and meta-competencies required for successful engineer in a changing environment. We present an approach to addressing these competencies in a distributed learning setting. During the past ten years, we have implemented the approach in a number of courses at Georgia Tech, University of Oklahoma, and Washington State University.

This paper is the first part of a four-paper series. In the second paper [52], we present the details of the latest implementation of the approach in two courses (AME 7540 and ME 503) jointly offered at University of Oklahoma and Washington State University during Fall 2011. The question for the semester for that semester was on the metacompetencies of identification and management of dilemmas. In the third paper [62], we discuss how we structured the course to help the students learn how to identify dilemmas. Finally, the fourth paper [65] is focused on student learning associated with the management of dilemmas.

5 ACKNOWLEDGEMENTS

We thank our industrial collaboration partners who, since 2009, have actively supported our efforts to transform education through guest lectures, sponsored projects, or donated hardware and software. We acknowledge the contributions of Jim Ryan and Shekar Kanetkar (MSC Software), Franz Dill and Don Breit (Procter and Gamble), Keith Asef (Hewlett Packard), Roger Burkhart (John Deere), and Nelson Baker (DLPE, Georgia Tech). Jitesh Panchal gratefully acknowledges the financial support from US National Science Foundation CAREER grant # 0954447.

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