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AC 2011-512: DESIGN EDUCATION FOR THE WORLD OF NEAR TOMORROW: EMPOWERING STUDENTS TO LEARN HOW TO LEARN

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Design Education for the World of Near Tomorrow: Empowering Students to Learn How to Learn

1. Introduction

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 [1,2]. Looking back at the past 20 years of engineering design and realizing how much the world has changed it becomes apparent that this change needs to be better reflected in the way engineering designers are educated [3-6]. Complex social networks, consisting of millions of individuals, have formed over the Internet through emerging Web 2.0 technologies, including blogs, discussion boards, etc. Information is readily available to everyone through the Web, anytime and anywhere. Individuals who have never met each other 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 will be the new normal. Their number one material to work with will be information and their generation is already being referred to as that of the knowledge workers.

Given this complex and dynamic environment, the key question we pose is: *How can we better educate the engineering designers of near tomorrow?* While there is a broad agreement that engineering education does have to change, there appears to be little tangible advice rooted in practice experience as to how exactly that change is best to occur. One step in the right direction that many educators agree with is that engineering education needs to be considered from a more holistic point of view [7]. 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. So, in essence, the big challenge boils down to educate students with respect to learn how to learn and to empower them to take charge of their own lives – in the context of the ever-increasing amount of subject matter to be covered. We believe that the competitiveness of the next generation of engineers in general will no longer be defined solely by their knowledge and skills. 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.

We believe that engineering education should be augmented with 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 [8, 32]. We have been professionally involved in engineering design and product development for many years and decided to approach this augmentation of engineering education from within the technical domain we are most familiar with. The ‘laboratory’ for this endeavor has been a graduate level engineering design course that is offered at Georgia Institute of Technology every spring, namely, *ME6102 Designing Open Engineering Systems*. We have jointly orchestrated this course for many years. In the following sections, an overview of this course, its context and content, the way it is structured and orchestrated, and in particular the fashion in which it serves as a vehicle and example for re-designing engineering education are presented.

In terms of context, our approach is focused on leveraging the relatively young, sometimes referred to as game-changing, paradigms of mass career customization, mass collaboration, open innovation, and crowd sourcing. From an educational and instructional perspective, our approach is anchored in the theory of collaborative/collective learning, the paradigm of mass customization applied to course design, and the concept of competency-based learning.

2. Globalization 3 and the world of near tomorrow

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 [8]. Examples of such paradigms include mass collaboration [8], collective innovation [9], collective invention [10], user innovation [11], crowd sourcing [12], open innovation [13], and community-based innovation [14]. While the most popular examples of community-based innovation come from open-source software (OSS) such as Linux, Apache, and Mozilla, many physical products are being developed through such principles. Examples include open-source 3D printers [15], electronics prototyping platforms [16], cell phones [17], cars [18], prosthetics [19], machine tools, robots, and other socially relevant design projects [20].

As alluded to before, in the era of Globalization 3, new organizational structures based on self-organizing communities are emerging to complement traditional hierarchies. According to Tapscott and Williams [8], the new principles for success in Globalization 3 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 can vary from the ones required for success in the Globalization 1.0 or Globalization 2.0 eras. Many involved in engineering education have shown that most current curricula focus on traditional organizational paradigms and business models. Hence, our grand challenge as innovators in engineering education is to address the following question: "*How should we prepare our students for the dynamic contribution-based Globalization 3 environment in which they will have to work?*" In the following, we present one approach we have been experimenting with that may serve as a step towards addressing this challenge.

3. ME6102 course content

As mentioned before, *ME6102 Designing Open Engineering Systems* is a graduate level design course offered at Georgia Institute of Technology. It is taken by students with diverse backgrounds from a variety of engineering and science disciplines. The course is offered in both live and distance learning modes. The student body comprises of participants from the Georgia Tech Atlanta, Savannah, and Lorraine (France) campuses as well as distance-learning students

from across the US. Most students take ME6102 after they have taken some introductory engineering design course (for example, ME6101 Engineering Design) in which they have become familiar with a systematic design approach, such as the one developed by Pahl and Beitz [21].

From a technical point of view ME6102 is concerned with the design of Open Engineering Systems (OES). Open Engineering Systems are defined as “*systems of industrial products, services, and/or processes that are readily adaptable to changes in their environment, which enable producers to remain competitive in a global marketplace through continuous improvement and indefinite growth of an existing technological base*” [22]. In addition, over the course of the semester students are introduced to a selection of design-related topics, including mass customization of products, design of product platforms, modular design, robust design, decision-making in design, and others (a syllabus may be obtained from authors).

One of the challenges in ME6102 is to determine the requirements for these traditional design-related approaches to work well in the context of the G3 world with its new, game-changing paradigms of as mass collaboration, open innovation, crowd-sourcing, and the like. In order to provide our students with a holistic picture, we believe that the core technical design-related content is best delivered in combination with a variety of guest lectures – often given by strategic leaders from industry – that focus on these new and game-changing paradigms and help put the design process into industrial/business context.

4. ME6102 Implementation in spring 2009

In this section we present a brief overview of the implementation of the scaffolded learning activities of ME6102 as they were implemented in spring semester 2009. 20 students were enrolled in the course and they were located in Atlanta, Savannah, and across the US. As explained before, a key objective in this course is for students *to learn how to learn*, in the context of the G3 world, and technical domain of engineering design. An at-a-glance overview of the way on which learning is facilitated in ME6102 through a number of scaffolded activities is presented in Figure 1.

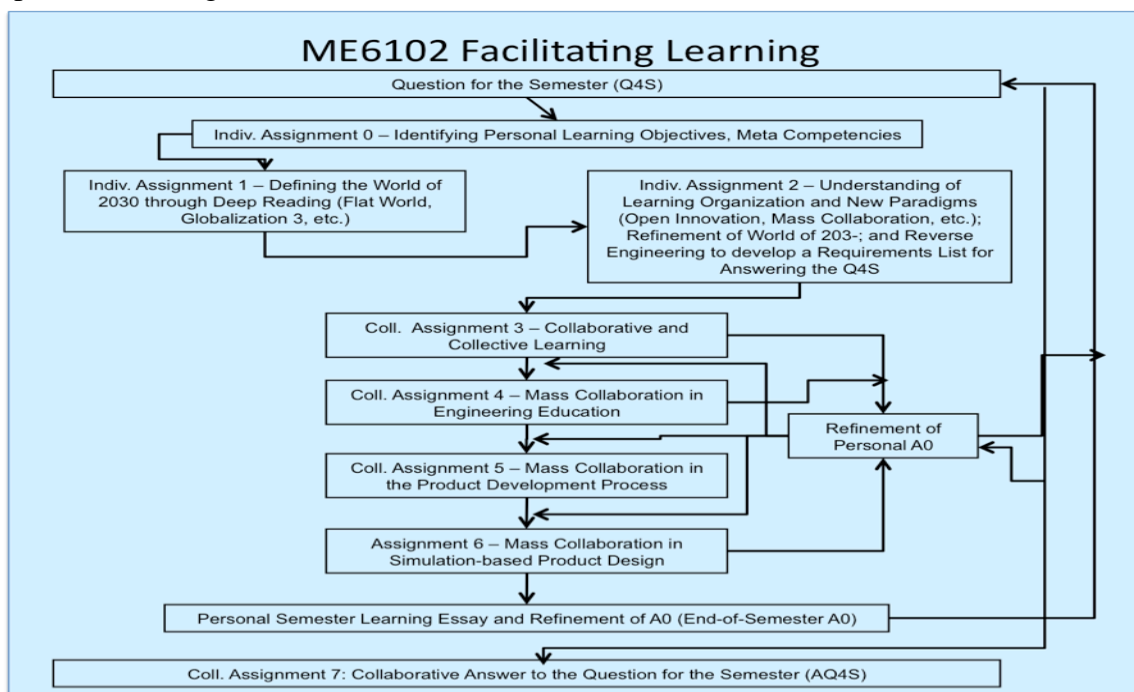


Figure 1: Facilitating Learning in ME6102

4.1 Question for the semester (Q4S)

In personalizing a course, the challenge for the course orchestrators is to keep the students' efforts aligned with the objectives and topics intended. In the pedagogical approach presented here, this is achieved through a scaffolded component. It consists of 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. In ME6102 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. Every student has to answer this question as a take home exam that is due at the end of the semester. The question for the semester assigned to the students in spring 2009 was:

"Imagine that you are operating a product creation enterprise in the era of Globalization 3 where individuals are empowered to participate in the global value network. Your brief is to identify the characteristics of the IT infrastructure to support technical collaboration that furthers open innovation."

This question served as a foundation for ME6102. All in-class and out of class activities were directed towards answering this question. To support the individual interests, the students were allowed to tweak and personalize this question according to their personal semester goals. The changes a student could make to the Q4S were limited and had to be approved by the course orchestrators. In a mass customized course this framing was particularly important to keep the students focused on their personal objectives. That way, the students could evaluate their work towards the answer of the Q4S and could prioritize their ideas.

4.2 Individual Assignment 0

In A0 students were required to identify the competencies they wished to develop in the context of ME6102, the Q4S, and the G3 world as well as associated learning objectives. Since the student's knowledge and experience continuously improved throughout the semester, these initial competencies and learning objectives several times had to be refined accordingly. The various steps of the original assignment A0 are presented in Figure 2. A representative example of what the outcomes of this assignment looked like is presented in Figure 3 below.

4.3 Individual Assignment 1

In A1 the students took a closer look at defining their world of 2030 and their views on what a manufacturing enterprise will look like 20 years from today. This was approached through "Deep Reading," Observe-Reflect-Articulate and Critical Thinking activities. Expected outcomes were (1) a vision for the engineering world of 2030; (2) a vision of product creation enterprises in the world of 2030; and (3) refined competencies and learning objectives.

Assignment 0

Identify Competencies

1. What is your view of a manufacturing enterprise in 2030? Leverage Lecture 01, Friedman, P&G.
2. Critically evaluate your response in Point 1 and then propose the competencies (in bullet form) that you believe are needed to be a successful designer in the world of 2030. Justify. Hint: See Slides 13 and 14, Lecture 2.
3. Critically evaluate the list in Point 2. This will require you to do a self-inventory of your competencies or lack thereof. List (in bullet form) the 5 competencies you propose to develop in ME6102.
4. Analyze the competencies listed in Point 3. Classify. Prioritize. Modify/refine. Propose an improved list of competencies you propose to develop. In context of Points 2 and 1 justify your proposed set of competencies.

Identify Learning Objectives

5. Analyze your response to Point 4. Respond to the following question (bullet form): For me to develop the competencies listed in Point 4 what do I need to learn? For each Competency identify the associated Learning Objectives. **Note: A Learning Objective must contain the word “learn” in it and include transformative words from Bloom’s Taxonomy** (see lecture 1).
6. Classify, refine the list. Prioritize, modify / refine and list your 5 Learning Objectives for this class. Justify.

Relate Competencies and Learning Objectives

7. Illustrate the relationship between the competencies identified in Step 4 and Step 6. Comment on the efficacy of the relationship.

Value

8. Analyze what you have written in Points 4 and 6 and answer the following questions: What is it you really wish to achieve as a result of taking this course? What have you learned as a result of doing this assignment? Hint: Summarize using transformative words from Bloom’s Taxonomy and associated competencies; see Slides 13 and 14, Lecture 2.

Figure 2: Fragment of Assignment 0: Competencies and Learning Objectives

4.4 Individual Assignment 2

In A2, the students built upon their previous assignment plus what had been covered in class over the first couple of weeks. Now their task was to identify what exactly it takes to answer the Q4S. In essence, answering the Q4S was their design problem and the answer to this question considered an Open Engineering System they were required to build.

The expected outcome of this assignment is a requirements list for an Answer to the Question for the Semester. To learn how to do this, the students start with reverse engineering the requirements list for Open Engineering Systems [22]. Then, they reverse engineer a requirements list for their answer to the Q4S, perform a gap analysis between both lists and refine their requirements list for the answer to the Q4S.

4.5 Collaborative Assignment 3

A3 was the first of the collaborative assignments. This time, the students were required to create a Virtual Learning Environment (VLE) for collaborative and collective learning in which to work on this and the following assignments. In addition to the technical aspects, this included forming a learning community in a distributed setting plus establishing policies regarding their collaboration and behavior. In other words, they had to build a small form of a learning organization. However, the concept of the Learning Organization in its traditional form is dated and needed to be augmented to meet the requirements of the G3 world. The expected outcome of A3 was a book chapter on ‘The Learning Organization in the context of the Question

1. How does ME6102 relate to learning organization?
2. What is the role of a learning organization in GLOBALIZATION 3?
3. How can CONNECT AND DEVELOP (C&D) be facilitated through constructs embodied in a learning organization?
4. How can MASS COLLABORATION based organizations benefit through constructs embodied in a learning organization?
5. How can OPEN INNOVATION be facilitated through constructs embodied in a learning organization?
6. How can you leverage the constructs presented in this lecture for ANSWERING THE Q4S?
7. Peter Senge's book is relatively old.
 - a. Are his views/model still valid?
 - b. What may a Learning Organization of the year 2030 look like?
 - c. What needs to be true to make ME6102 (and ME575) a distributed Learning Organization?

On Facebook, the students successfully addressed all of the above questions. Then, they collaboratively wrote a book chapter about their findings using GoogleDocs. The specific question posed by P&G was also addressed, and hence a small-scale consulting project conducted in a mass collaborative fashion.

4.6 Collaborative Assignment 4

The topic for A4 was Mass Collaboration in Engineering Education. The students were tasked to identify and analyze Web 2.0 technologies with regard to their appropriateness for professional mass collaborative work. This included IT requirements, video and audio capabilities, safety issues, storage requirements, modularity and scalability, ease of use, etc.

4.7 Collaborative Assignment 5

In A5 the students were to look into the topic of Mass Collaboration in the Product Development Process. This included an analysis with regard to the following phases: 1) Idea Generation, 2) Idea Screening, 3) Concept Development and Testing, 4) Business Analysis, 5) Beta Testing and Market Testing, 6) Technical Implementation, and 7) Commercialization. In addition, methods of Mass Collaboration between the various functional units of corporate enterprises were investigated and requirements for a successful implementation identified.

4.8 Collaborative Assignment 6

The topic for A6 was the application of Mass Collaboration in virtual product realization environments through the utilization of Simulation-based Design. Question addressed included: What should the virtual product realization environments for mass collaborative product development look like? What will the role of 3-D CAD be in these environments? What kinds of standards are required for design information management in mass-collaborative scenarios? How can multi-disciplinary analyses and design changes be coordinated in a mass-collaborative product development scenario?

4.9 Assignment 7 and the answer to the question for the semester (A2Q4S)

In A7 the students were required to put together all the well-scaffolded pieces they had worked on during the semester. That is, they collaboratively had to write a complete book in which each chapter was dedicated to one of the assignments. The difficult task here was to tie everything together and create a coherent train of thought, starting from the background information on Friedman's flat world, Procter and Gamble's Connect and Develop approach for Open Innovation, Bloom's Taxonomy of Learning, the Q4S, the topics of the subsequent assignments as well as the industrial mini-consulting projects that were embedded into the assignments. In addition, the students had to answer the Question for the Semester that was posed in the first class on day one. They had to do this in two ways: first, they all answered their individually tweaked questions, and then they had to converge to a collaborative answer anchored in their individual ones.

4.10 A0-EOS and self grading

The final stage of the course was to close the loop with regard to what was learned. The students were required to revisit their A0 submissions and take stock of how much each of the learning activities throughout the semester had actually helped them to attain the desired competencies and meet the corresponding learning objectives. *To what level of Bloom's Taxonomy had they managed to climb and to what degree did they learn how to learn?* This process of reflective practice [28] was presented to the students by means of A0-EOS, an extended end-of-semester version of the original Assignment 0 (see Figure 4).

In addition to revisiting questions 1 through 8 of A0 (see Figure 2), the students were asked 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 ME6102 Learning Organization. Finally, based upon this self-reflection, the students were asked to propose a grading scheme for evaluating their own work as well as that of their peers. This included developing a comprehensive assessment rubric [34] 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 believed they had earned.

5. Educational frame of reference

In the following sections we introduce and explain the educational frame of reference of the ME6102 learning environment and associated activities. This framework is anchored in Bloom's Taxonomy of Learning and aimed at fostering deep learning among students through problem-based instructional techniques and student-centered approaches to learning [23].

5.1 Blooms taxonomy of learning

In 1956, Bloom [24] developed a classification of levels of intellectual behavior important in learning. Bloom identified six levels within the cognitive domain (see Figure 5), 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. These six levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation.

Assignment 0 – End of Semester

...

A0 Completion - Individual

10. Revisit Value = Utility / Time Invested
Summarize ...
Assignment 1: Summarize Part 6
Assignment 2: Summarize Part 4
Assignment 3 through 6: Summarize Part 3
11. In tabular form, in the context of a learning organization, outline the strategy that you followed in defining your “mental model” for Assignments 3 through 6 AND your contributions to the collaborative assignment.
12. In tabular form summarize your contributions to Assignments 3 through 7 under the following headings:
 - a. Themes / ideas proposed by you and adopted by the team ...
 - b. Themes / ideas proposed by others that were adopted by the team ...
 - c. Rate the contribution of others¹: A – above average. B – average. C – below average. You are encouraged to use + and – for the grades you assign. Justify.
 - d. In the context of 12 c rate your own contribution: A – above average. B – average. C – below average. Justify.
13. In tabular form, please convey how you progressed in attaining your competencies and learning objectives throughout the semester.
14. In graphical format, please convey the degree to which you attained the identified competencies and learning objectives.
15. Analyze what you have written in Steps 10 through 14. Then, critically evaluate your performance (in terms of competencies and learning objectives) throughout the semester; be sure to use action words from Bloom’s taxonomy. Comment on the level of attainment in Step 14, what you would do differently if you had to do it over, and plans for the future.

Grade for A0 End of Semester

16. Reflect on your performance in this class throughout the semester. In tabular form, please suggest a grade for yourself in the following categories and justify²:
 - a. Contribution to the collective Question for the Semester. Justify.
 - b. Degree to which you attained your competencies and learning objectives and why.
 - c. Degree to which you learned what you would do differently and why.
17. Overall grade you award yourself for this submission. Not all items are equally important to determine your grade for the course. You may weight items 16a through 16c as shown below.
 - 16a - 30 to 50%
 - 16b – 30 to 50%
 - 16c – 10 to 20%

¹ A+ (4.3). A (4.0). A-(3.7). B+(3.3). B (3.0). B-(2.7). C+(2.3). C (2.0). C-(1.7). D (1.0). F (0.0)

² Be sure to reference elements of your responses to Items 10 through 15.

Figure 4: Fragment of Assignment 0 – End of Semester (A0-EOS)

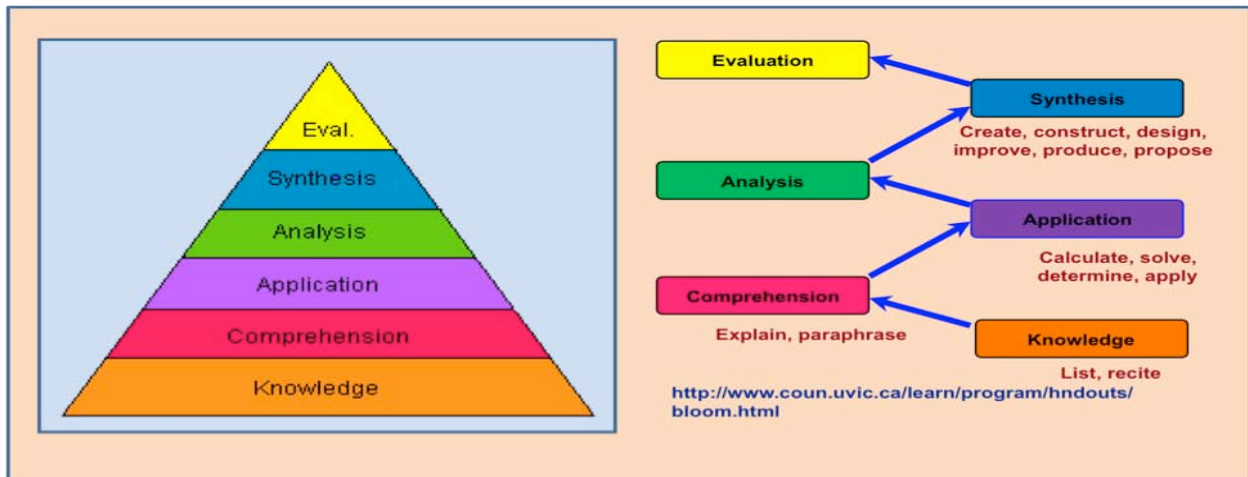


Figure 5: Bloom's Taxonomy of Learning

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.

At the beginning of ME6102 all students are introduced to Bloom's Taxonomy and it is emphasized that our intention is to help our graduate students reach the top levels of the taxonomy. Interestingly, Bloom's Taxonomy resembles Maslow's famous Hierarchy of Needs [33] if competencies are considered needs in terms of becoming successful in the G3 world. While there are many other taxonomies of learning that we could have used for the same purpose we decided to choose Bloom's traditional taxonomy simply because it is something that, based on our experience, engineering students find natural and easy to grasp.

5.2 Collaborative and collective learning

The pedagogical approach adopted in ME6102 embraces elements of collaborative, cooperative, and collective learning. It has been presented in detail in [23]. Research suggests that these instructional approaches foster a deeper understanding of the course content, increased overall achievement of desired learning outcomes, improved self-esteem and higher motivation among students. A brief overview of these instructional approaches with a focus on those aspects most relevant to our pedagogical approach is presented below.

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.

5.3 The learning organization

Another key pillar of our educational framework is 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 Peter Senge in his famous 1990s book 'The 5th Discipline' [25]. 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. A brief overview of these, taken from [26], is presented below.

Systems thinking: The idea of the learning organization developed from a body of work called systems thinking. This is a conceptual framework that allows people to study businesses as bounded objects. Learning organizations use this method of thinking when assessing their company and have information systems that measure the performance of the organization as a whole and of its various components. Systems thinking states that all the characteristics must be apparent at once in an organization for it to be a learning organization. If some of these characteristics is missing, then the organization will fall short of its goal.

Personal mastery: The commitment by an individual to the process of learning is known as personal mastery. There is a competitive advantage for an organization whose workforce can learn quicker than the workforce of other organizations. Individual learning is acquired through staff training and development, however learning cannot be forced upon an individual who is not receptive to learning. Research shows that most learning in the workplace is incidental, rather than the product of formal training, therefore it is important to develop a culture where personal

mastery is practiced in daily life. A learning organization has been described as the sum of individual learning, but there must be mechanisms for individual learning to be transferred into organizational learning.

Mental models: The assumptions held by individuals and organizations are called mental models. To become a learning organization, these models must be challenged. Individuals tend to espouse theories, which are what they intend to follow, and theories-in-use, which are what they actually do. Similarly, organizations tend to have ‘memories’ which preserve certain behaviors, norms and values. In creating a learning environment it is important to replace confrontational attitudes with an open culture that promotes inquiry and trust. To achieve this, the learning organization needs mechanisms for locating and assessing organizational theories of action. Unwanted values need to be discarded in a process called ‘unlearning’.

Shared vision: The development of a shared vision is important in motivating people to learn, as it creates a common identity that provides focus and energy for learning. The most successful visions build on the individual visions of the employees at all levels of the organization, thus the creation of a shared vision can be hindered by traditional structures where the company vision is imposed. Therefore, learning organizations tend to have flat, decentralized organizational structures. The shared vision is often to succeed against a competitor, however Senge states that these are transitory goals and suggests that there should also be long-term goals that are intrinsic within the company.

Team learning: The accumulation of individual learning constitutes team learning. The benefit of team or shared learning is that people grow more quickly and the problem solving capacity of the organization is improved through better access to knowledge and expertise. Learning organizations have structures that facilitate team learning with features such as boundary crossing and openness. Team learning requires individuals to engage in dialogue and discussion; therefore team members must develop open communication, shared meaning, and shared understanding. Learning organizations typically have excellent knowledge management structures, allowing creation, acquisition, dissemination, and implementation of this knowledge in the organization.

An obvious issue with introducing this paradigm of the Learning Organization into the classroom environment of ME6102 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 LO 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.

5.4 Scaffolding and reflective practice

Scaffolding: One of the primary goals in ME6102 is to provide individualized learning in a collaborative environment. This is realized through four instructional cornerstones: scaffolding, reflective practice, customization, and 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 “Question for the Semester” (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 diverse knowledge created in the preceding parts is captured in the collaboration part. While answering the “Collaborative Question for the Semester” the students learn and work in a mass collaborative environment that provides the opportunity to create new knowledge by combining the diverse knowledge in the personalized section of the course.

Reflective Practice through Observe-Reflect-Articulate: In a mass customized course the articulation of individual learning is crucial since it is the prerequisite for the evaluation of the progress. Usually students are not used to this and have difficulties with the articulation of their learning. They are used to show 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, in ME6102, the Observe-Reflect-Articulate (ORA) construct [27] 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 Donald Schon [28].

5.5 Learning essays and group project

Learning essays are encouraged weekly submissions in which students review and explore topics from the lectures in context of their individual semester goals. To guide 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 in ME6102 is graded till the end of the semester (we provide formative assessment 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 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 show that they really proceeded in achieving their semester goals.

The students are expected to validate a part of their answer to the Q4S through a group project. The validation is carried out using a construct called Validation Square [29, 30], which is developed for validating design methods. Validation is an important aspect of the course because it helps students to learn how to critically evaluate their proposed answer to the Q4S. The students are free to choose the topic of the project related to their research or other personal interests. Examples from the past are “human centered design of a bicycle through a simplified CAD interface for customer interaction” and “motivation and incentive models in online communities and mass collaborative projects”. The typical group size is two to four members. This cooperative learning experience is integrated into the presented approach to increase the depth of learning through group learning and discussions.

6. Closing

In this paper, we presented our approach towards augmenting engineering education in one way that may help empower our students to become leaders in the world of near tomorrow. We documented how we approached this from within our own technical discipline of engineering design.

Revisiting the question posed at the beginning of this paper and reflecting on the observations made over the course of the semester, we draw the following conclusions: In addition to ever evolving knowledge and technological progress, engineering education is impacted by significant changes in the business environment due to Globalization 3. These changes need to be addressed in our curricula. While technical (core) competencies still are the foundation for success, a number of meta-competencies are required to succeed in the new world of near tomorrow. These include an ability to learn how to learn, an ability to form learning communities, and an ability to collaborate in distributed corporate settings, across countries, continents and cultures. For this to come true, those engineers who wish to become leaders in the world of near tomorrow need to learn how to break with traditional 20th century business models and adjust to what is needed to become a value-adding factor in an interconnected world. In terms of paradigms, this may be considered a shift from ‘team to win’ to ‘share to gain’. The engineer of near tomorrow, a G3 knowledge worker, needs to become a master in creating new knowledge based on a multitude of information and information sources [32].

Overall, the approach described in this paper has worked well. We have experimented with it four times between 2007 and 2010 and approximately 75% of our students fully accomplish the desired learning objectives. As explained in Section 4.10, at the end of the semesters the students were asked to develop a self-grading scheme and propose and justify their own grades. This activity was built into the course as a means to toward achieving level 6 in Bloom’s taxonomy (evaluation). We were pleased to see that the self-grading for 80% of the students was very much in line with the grades the course orchestrators determined.

At the beginning of the course, many students dislike the idea of having to revisit a specific topic (the Question for the Semester) again and again. However, as the semester progresses and as the students begin to understand and appreciate the value of continuous formative assessment and

reflective practice they get accustomed to this. As far the instructor engagement is concerned we have to acknowledge that this course demanded a lot of time from the orchestrators. A thorough and successful implementation of the approach described in this paper requires effort that goes beyond traditional lecturing along the lines of ‘the professor’s notes become the students’ notes’. Having said that, and recognizing that research often times takes over our daily business, education still is at the heart of our profession and hence should be practiced with passion – just as our research. With time and experience though, the effort for offering this course decreases, especially if appropriate rubric sheets for marking/grading are used. In summary, we have observed an increase in both student engagement and learning. We are particularly pleased about positive feedback from former students who are now in industry and appreciate and value of what they experienced in this course. What is currently missing is a thorough long-term assessment of our approach. As part of our future work we intend to investigate what exactly the students actually take away from the course beyond the core technical design content.

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