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Fostering Collaborative Learning and Mass-Customization of Education in a Graduate Engineering Design Course*

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The rapid progress of globalization has lead to many unprecedented changes in the world in which our students will practice. New product development paradigms such as mass collaboration are redefining the way in which products are realized. The authors believe that in the light of these changes, new approaches to educating the next generation of engineers are needed. Towards this goal, the authors present a pedagogical approach to allow students to experience mass collaboration and to improve their understanding of emerging trends in product development. The approach is designed to foster collective learning and to apply mass customization in education. It is presented in the context of a graduate engineering design course—'Designing Open Engineering Systems'. Two of the main features of the approach are: (1) providing the students with the opportunity to define their own learning goals, and (2) posing a broad question to which the students are required to develop an answer by the end of the semester. All activities of the course are geared towards answering this question—both individually and collectively. Collective learning is facilitated through semester-long continuous development of a collaborative answer to the Q4S by the entire class. Mass customization of education is achieved by having students define their personal semester goals as well as personalizing their answer to the Q4S. A web-based collaborative learning framework is developed for this course using social networking tools to facilitate communication, and to simulate a mass collaborative environment. The authors believe that such pedagogical approaches are essential for developing a foundation for next generation educational environments.

Keywords: mass collaboration; collective learning; educational mass customization; engineering design; question for the semester; social networking

GLOBALIZATION AND EDUCATION

THE RAPID PROGRESS OF GLOBALIZATION [1] has lead 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 on the vision of the engineering profession for the year 2020 [2]. A follow-up report [3] on how to educate the engineer of 2020 came out 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.

In order to accommodate engineering education to the challenges posed by a flat world, new educational models encompassing the design of programs and courses, novel ways to deliver them, and associated IT-infrastructures have to be developed [4]. In response to Friedman's question, the George W. Woodruff School of Mechanical Engineering at Georgia Tech Savannah is committed to developing rigorous, innovative, experiential educational programs that integrate disciplines, engage students in the excitement of learning, motivate their passion for positive societal impact, and develop leaders for the future. In this context, a pedagogical approach towards collaborative learning and mass customization of engineering education in a globally dispersed educational setting is presented in this paper.

The pedagogical approach features elements such as collaborative, cooperative, and collective learning. It accommodates recent changes in e-learning and the way society uses contemporary learning technologies such as educational applications of Web 2.0.

Consisting of three major parts—scaffolding, mass customization and collaboration—the presented approach supports a variety of learning

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styles. In this paper, the implementation of this pedagogical approach is described in the context of ME6102: 'Designing Open Engineering Systems', which is a graduate engineering design course offered at Georgia Institute of Technology.

The paper is organized as follows. First, it is shown how the scaffolded part of the course sets the frame of topics with the lectures and mandatory submissions in a defined form. It is arranged as follows. The mass customized aspect of the course, then described, is realized with individual submissions, called 'learning essays'. Students work either on topics presented in class or related topics of personal interest. This created knowledge is used in the collaboration part of the course, which consists of a team project and a collaborative submission of the entire class. The collaborative learning aspect and its implementation in the course are then discussed.

An overview of the theoretical foundations of the educational, instructional, and technological aspects of this approach is presented in the following section.

EDUCATIONAL BACKGROUND AND INSTRUCTIONAL TECHNIQUES

Mass collaboration and Web 2.0

According to Friedman [1], we have reached the era of Globalization 3.0, in which individuals have the power to collaborate and compete globally. The driver for Friedman's Globalization 3.0 is 'the newfound power for individuals to collaborate and compete globally'. Globalization 3.0 has led to a new paradigm called mass collaboration [5]. Mass collaboration is the phenomenon that has resulted in breakthrough products such as Linux and Wikipedia. The internet technologies that facilitate mass collaboration are referred to as Web 2.0.

A key characteristic of Web 2.0 is the harnessing of collective intelligence. According to Romani [6], Web 2.0 refers to a second generation of internet-based services, such as social networking sites, wikis, communication tools, etc. that emphasize online collaboration and sharing among users. Web 2.0 offers a significant potential to support the consolidation of a new paradigm of education. It empowers users and providers with a platform to gather, share, and enrich knowledge. Web 2.0 is centered in knowledge generation and is not limited to the use and sharing of information. It promotes the transformation of learning experiences into personally usable, practical knowledge, and helps learners to present results of this transformation to others. Web 2.0 applications support the ubiquity of communication and knowledge production, qualities that are essential for globally-distributed education for the 21st century [7]. Well known examples of Web 2.0 technologies that can be used to generate and distribute knowledge in the educational context include: wikis, repositories, blogs, and podcasts. An overview of current Web 2.0 technologies in the context of e-learning is given in [8]. In the approach presented in this paper, the Web 2.0 technologies are used to facilitate collective learning.

Educational background: Approaches to learning

Learning is mainly characterized by an intention, which is usually coupled with a process. There are different approaches to learning that a student may adopt—'deep learning', 'surface learning' and 'strategic learning'. 'Surface learning' is just to cope with the course requirements. Students only focus on the superficial aspects of what is being taught. The process behind surface learning is that of reproducing information, e.g., by memorizing facts and procedures routinely. In adopting a 'strategic approach' to learning, the emphasis is placed on achieving the highest possible grades with minimum personal input. The process that underlies strategic learning is that of organization, i.e., by managing time and effort effectively. 'Deep learning' is to thoroughly understand what is being taught. The focus is on what is 'signified', what the message is about, and what things mean. Deep learning actively involves establishing relationships between ideas, past experiences, and the real world. Deep learning processes can be stimulated through problem-based activities, particularly in educational environments that foster collaborative and cooperative learning [4]. In describing a learning organization, Senge [9] suggests that deep learning is one of the key motivators and therefore he suggests an organization where members identify their personal visions. Those visions are then synthesized to a shared vision in order to achieve team learning. In this paper, the authors present a pedagogical approach that facilitates deep learning by building on Senge's concepts of learning organizations.

Collaborative, cooperative and collective learning

As alluded to earlier, the pedagogical approach presented in this paper embraces elements of collaborative, cooperative, and collective learning. 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 in the rest of this section.

The phrase *collaborative learning* stands for a variety of student-centered educational approaches that involve joint intellectual effort by learners and orchestrators. 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 [10]. Johnson and coauthors define *cooperative learning* as 'the instructional use of small groups so that students work together to maximize their own and each other's learning' [11]. It is based on the social interdependence theories developed by Lewin and Deutsch [12], which explore the influence of the structure of social interdependence on individual interaction within a given situation, which, in turn, affects the outcome of that interaction [13, 14]. In a later publication, Johnson and coauthors [15] define cooperative learning as 'an instructional paradigm in which teams of students work on structured tasks (e.g., homework assignments, laboratory experiments, or design projects) under conditions that meet five criteria: (1) positive interdependence; (2) individual accountability; (3) face-to-face interaction; (4) appropriate use of collaborative skills; and (5) regular self-assessment of team functioning'.

In cooperative learning, groups of students usually work together in order to understand something, grasp a meaning, or develop a solution to a problem. According to Smith and MacGregor [14], 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 of 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 can also refer to a collection of tools that 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. For a more detailed overview of collaborative learning and current collaborative learning techniques please refer to [14] and [16], respectively.

The term *collective learning* is not uniquely defined and widely used in the context of vocational education. According to de Laat and Simons [17], 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.

Personalization, mass customization and mass collaboration in education

Mass customization in engineering means to design a product in order to be able to customize it for the needs of individuals while maintaining costs and productivity close to those of mass production [18]. The primary benefit of this is a better fulfillment of the individual customer's needs and requirements. The concept of mass customization can also be applied to engineering education. Williams and Mistree [19] describe an engineering design course that fosters mass customization for the students' individual interests and learning styles. According to Cheng [20], 'the major implication of individualization in higher education is to maximize motivation, initiative, and creativity of students and professors in tertiary learning, teaching, and research through such measures as implementing individualized educational programs; designing and using individualized learning targets, methods, and progress schedules; encouraging students to be self learning, self actualizing, and self initiating; meeting individual's special needs; and developing students' contextualized multiple intelligences'. Freund [21] argues that education and training should be customized by accounting for individual personality differences. Nistor [22] presents six steps for mass customizing learning environments—'a) scope definition of the educational institution, b) contact with the learner, c) interaction with the learner and definition of a learner profile, d) creation and adaptation, e) use of learning environment, and f) formative evaluation with positive feedback onto the learner profile and the knowledge basis'. Gabriel and co-authors [23] address mass customization in education from a modularity and standardization perspective. Despite these initial efforts on applying the mass customization concepts to education, most of the engineering courses are still mass produced.

In addition to mass production, one of the limitations of current engineering courses is that emphasis is mainly placed on the aspects of analysis. However, to enable students to 'self-learn' in this mass customized environment a focus on additional skills is crucial. Bloom [24] shows that for the creation of new knowledge, several steps beyond analysis are needed. Those require critical thinking, synthesis and evaluation skills. The analysis and synthesis of existing knowledge in order to create new knowledge, is also crucial for innovation. So in this setting the students gain abilities that help them to be self learning and innovative.

By supporting personalized learning, mass customized courses lead to the development of a diverse set of knowledge and competencies in a class [19, 22]. Existing approaches however are limited to this step. They do not take advantage of the available diversity within the entire group. In the pedagogical approach presented in this paper a tool is introduced that allows repetition of the steps of analysis, synthesis, and evaluation at a group level through mass collaboration and collaborative learning. Utilizing the diverse learning in order to create new knowledge and insight for the students is the logical consequence of mass customization of a course. This is also an important experience for the students. As engineers they will work in multi-disciplinary teams consisting of individuals with different skills, experience and professional background. In addition to that, the ability to take advantage of the diverse knowledge in the team is crucial for designing innovative and breakthrough engineering systems.

The aspects reviewed in this section are applied in the presented approach. The approach and an implementation are presented in the next section.

ME6102: AN EXAMPLE OF COLLECTIVE LEARNING AND MASS CUSTOMIZATION IN A GRADUATE DESIGN COURSE

ME6102 course overview

ME6102—'Designing Open Engineering Systems'—is a graduate engineering design course offered at the George W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology.

The content of the course is based on three cornerstones: Globalization 3.0 [1], Mass Collaboration [5] and Open Engineering Systems [25]. The emphasis is on developing a comprehensive multidisciplinary understanding of the future world. 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).

The course is aimed at providing an opportunity for students to learn how to create knowledge rather than merely learning how to solve problems encountered in design. In this course, emphasis is placed on problem identification and formulation in a rapidly changing world that is defined by Globalization 3.0. The course setting provides the opportunity for student to learn how to:

- identify opportunities for creating new systems and improving existing systems in the age of global mass-collaboration;
- identify the competencies required to succeed in a changing marketplace and learning how to gain those competencies;
- design open engineering systems in the presence of uncertainty from a decision-based perspective, i.e., to design systems with characteristics consistent with their natural life-cycle dynamics;
- manage uncertainty and complexity in systems and associated design processes;
- make tradeoffs needed to coordinate multiple objectives associated with the design of open engineering systems;
- develop the ability to evaluate literature critically and use this analysis to identify research issues worth investigating;
- continue learning about designing.

ME6102 is offered to students from many departments of Georgia Tech, independent of their location. In Spring 2008, ME6102 was taken by students at different Georgia Tech campuses—Atlanta, Savannah, and Lorraine (France)—and also by distance learning students who were located all over the world. The course is orchestrated by a team of two faculty members, one located in Atlanta and the other faculty member in Savannah. Each lecture is given by one of the faculty members. To reach all students, synchronous and asynchronous education techniques are incorporated. Atlanta and Savannah-based students attend the in-class lectures in a video conference set up; that means that if the lecture is given in Atlanta, the students in Savannah are connected through a video conference technology and vice versa. The lectures are recorded and uploaded so that all students can access them online at any time. This is the same for modules which are provided by guest lecturers. In addition to 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. The online forum also enables communication analogous to social networking websites such as Facebook and LinkedIn.

ME6102 course structure

The primary goal for developing the pedagogical approach presented in this paper is to provide an opportunity for personalized learning in a group setting. To customize the course, it is important to require the students identify their personal goals for the semester. In ME6102, 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 details of personal learning goals are presented below.

Having identified the students' personal goals, the course orchestrators structure the course using three instructional cornerstones: *scaffolding*, *customization* and *collaboration*. A combination of these uses a variety of educational approaches to foster deep learning among students. In Fig. 1, the relations between the different components of the course are depicted. The scaffolded part frames the content of the course with the 'Question for the Semester' (Q4S) and various assignments. The assignments are structured (scaffolded) and provide opportunity for individualization. This ensures that everybody in the 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 used to convey core course content and also cover additional aspects that may help students with their assignments and learning essays. 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 generated in the personalized section of the course.

Scaffolding of ME6102

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 associated assignments that are scaffolded towards the answer of this question (see Fig. 1).

In the first lecture, the Q4S is posed. 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 semester 2008 reads as follows:

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 2020 in such an environment?
b) How do you see yourself and your company operating in this world of 2020? 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 2020? 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 2020 look like?
f) What kind of a product realization method is necessary for your world of 2020? Please provide phases and steps of the method.

This Q4S serves as a foundation for ME6102. All in-class and out of class activities are directed towards answering this question. To support their individual interests, the students are allowed to tweak and personalize this question according to their personal semester goals (see below). The changes a student can make to the Q4S are limited and have to be approved by the course orchestrators. In a mass customized course this framing is

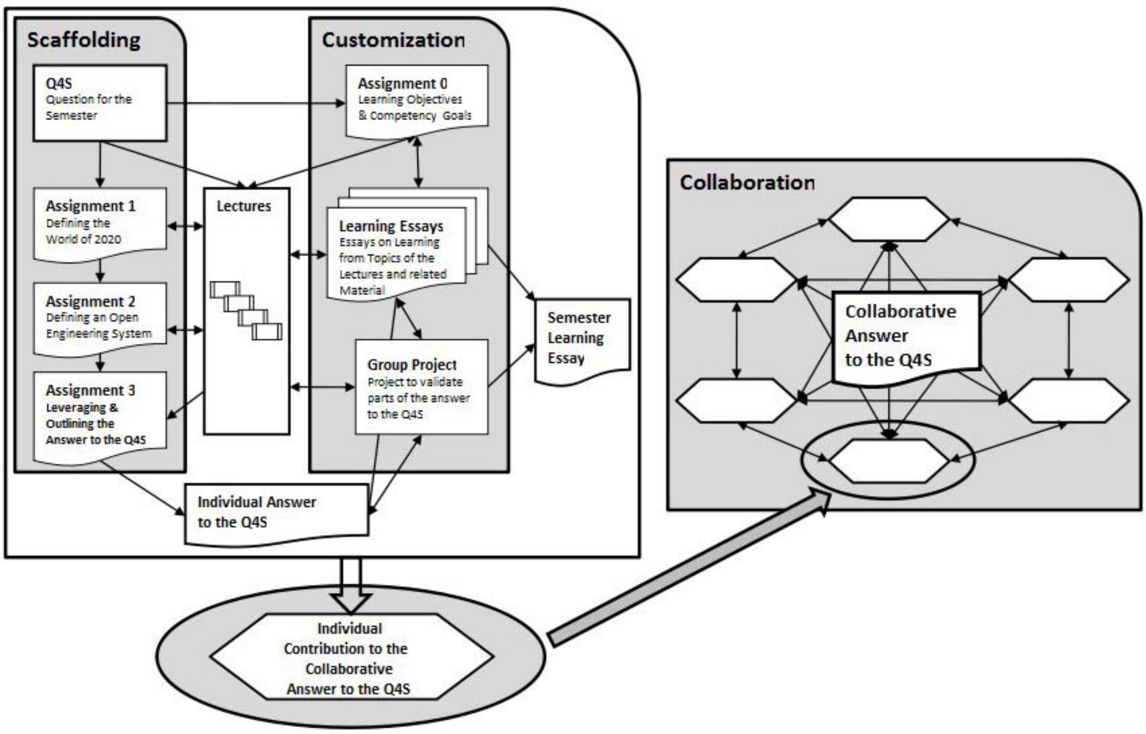

Fig. 1. Structure and information flow in ME6102.

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.

> During this semester I realized the importance of prioritizing my tasks and estimate their value towards my objectives. This course gave me a great opportunity to develop this ability.
>
> *Excerpt from a student's Semester Learning Essay*

The aforementioned scaffolding of the course through assignments is shown in Fig. 2. The assignments are designed to guide the students through the required literature and material needed to understand the big picture on which the question has to be answered. The assignments contain the following content: in Assignment 0, the students are asked to list their personal semester goals, which consist of learning objectives and competencies they wish to develop throughout the duration of this course. In Assignment 1, the students are asked to critically review Friedman's Globalization 3.0 [1] and Tapscott's *Wikinomics* [5]. The goal is the development of a vision of 2030 and the elaboration of a requirements list for a successful business in 2030. In Assignment 2, the students develop an individual definition of an 'Open Engineering System' after reviewing the paper 'Mass Customization in the Age of Information: The Case for Open Engineering Systems' by Simpson and co-authors [25]. In this assignment, the students gain the technical foundations for answering the question for the semester. The outcome of this assignment is a framework for designing open engineering systems. Assignment 3 involves the development of a project proposal where the students identify a project that is used to validate their answer to the Q4S. Assignment 3 also involves setting up of the collaborative answer to Q4S and identifying the aspects of the collaborative answer on which each individual will focus. Assignment 4 includes a critical review of two 'best practices' (discussed in the following section) of Assignment 1 and Assignment 2. Based on this review, the students are also asked to outline their individual answer to the Q4S. Finally, in Assignment 5, the students develop a skeleton for their answer to the Q4S. The orchestrators of the course continuously provide feedback (formative assessment) to the students. The feedback helps the students to refine their answer before the end-of-semester submission.

A further example for the scaffolding in ME6102 is a special assignment on the occasion of the World Economic Forum annual meeting. The students are asked to choose two of the discussions or speeches presented at the World Economic Forum (WEF) meeting based on their personal semester goals. The students are also asked to provide a rationale for their choice of the modules and the value towards answering the Q4S. This assignment is included to help students understand the present and realize the importance of speculating about the future. The results of this exercise serve as a basis for the students' vision of the world of 2030 in Assignment 1.

Mass customization of ME6102—Personalized learning in a group setting

Mass customization in education allows catering for the student's individual needs, skills and interests. This not only leads to a higher motivation of the students but also to a better and holistic individual education and deep learning. In ME6102, the orchestrators apply a similar approach to mass customization as presented by Williams and Mistree [19]. The key for providing a personalized learning experience in a group setting is an intensive two-way communication between students and orchestrators. Therefore the course orchestrators have to get to know the students and their personal semester goals. That way the educators can identify the needs and provide individual guidance.

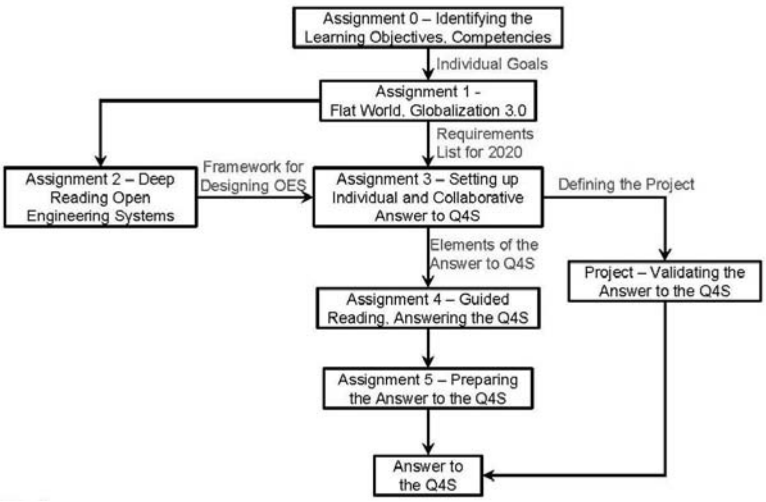

Fig. 2. Scaffolding of assignments to help students answer the Q4S.

In the presented approach, the students' objectives are captured through Assignment 0, which is due after the first week of class. The students are asked to provide a brief self-introduction, their expectations of taking this course and their personal semester goals (learning objectives and competencies). They are asked to list five *learning objectives* they want to achieve and five *competencies* they want to gain during the course of the semester. Learning objectives are clear formulations of what a student wants to learn and are usually related to acquisition and creation of knowledge.

> I want to learn what an open engineering system is and how to design engineering systems that are solutions to the problems of the future.
>
> *Example of a learning objective*

Competencies are defined by Jones and co-authors [26] as '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'. To help the students formulate the competencies they want to gain, Bloom's taxonomy [24] is introduced. Bloom describes the process of learning and creation of new knowledge in a taxonomy consisting of six levels of competencies that are from least to most complex: Knowledge, Understanding, Application, Analysis, Synthesis, and Evaluation. Where in most courses only the first three or four levels are addressed, the approach presented here is focused on the top three levels: Analysis, Synthesis and Evaluation; these are the steps where new knowledge is created. To internalize this concept, the students are asked to formulate their competencies along these levels of Bloom's taxonomy.

> I want to gain the ability to list (knowledge), compare (analysis) and assess (evaluation) my tasks and their priority in order to manage my time by creating (synthesis) an appropriate plan of action according to this judgment (evaluation).
>
> *Example of a competency*

In this paper, both learning objectives to be achieved and competencies to be gained are referred to as the students' personal semester goals.

This assignment helps the students realize what they really want to learn. They start each submission by stating their personal semester goals and evaluate their progress towards achieving them. It is important that the students accept Assignment 0 as a 'living document' that can be modified throughout the semester if they realize that their goals are changing.

> I want gain the ability to analyze a problem and derive the influence of uncertainty and complexity as well as the ability to model these disturbances to allow a design of robust solutions.
>
> Originally this competency was set up towards my thesis. But I realized that I want to concentrate more on the new possibilities of Globalization 3.0 such as mass collaboration in this course. So I maybe have to tweak this competency goal a little bit:
>
> I want gain the ability to analyze a problem or opportunity and derive the influence of complexity as well as the ability to create a set of appropriate assumptions to analyze the problem along them in several steps. I also need the ability to synthesize and evaluate these analyzes afterwards.
>
> *Example of a change of a personal semester goal*

Assignment 0 is the foundation for a bi-directional communication between the students and the orchestrators. This assignment helps the orchestrators to identify the goals and needs of the students. According to these needs the content and presentation style of the lectures are customized. Knowing the personal semester goals of a student helps the orchestrators to personalize feedback on all submissions. By identifying and stating their personal semester goals the students also develop a sense of commitment and self responsibility which is crucial for the success of a mass customized course [27].

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 demonstrating the outcomes of their learning activities during traditional 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 [28] is introduced to the students at the beginning of the semester. It consists of three phases [19]:

1. *Observation*, in which information that is gathered from various sources is stated;
2. *Reflection*, which starts with a question, and the background knowledge and experiences are called upon to generate new ideas and connections towards addressing the question;
3. *Articulation*, in which new conclusions are drawn and lessons learnt are explained.

By following these steps during the submissions the students internalize the process of learning and deeply learn how to learn.

Customized feedback

In ME6102 summative assessment is not used until the end of the semester. In other words, no grades are given until the end of the semester, so that the students can concentrate only on their progress towards their personal semester goals. Instead, the orchestrators provide individual feedback by means of formative assessment on all submissions throughout the semester. Through Assignment 0, the orchestrators get to know the students and thus are able to provide individual feedback on all submissions according to the students' individual semester goals. To remind both the student and the orchestrator of these goals the students state them at the beginning of all learning essays and assignments and evaluate their learning with regard to these goals. This means that the students get constructive feedback that helps them observe, reflect, learn, and make progress towards their individual semester goals.

Students are expected to record the comments they get on their work in a journal and demonstrate that they use them in the following submissions. In doing so, the students can better realize their progress, which can increase their motivation.

Learning essays

Learning essays are weekly submissions in which the students usually review and explore topics from the lectures in the context of their individual semester goals. To guide the students, at the end of each lecture specific 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 until the end of 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 their individual feedback and provide guidance (formative assessment).

A core aspect of the learning essays is that the students apply and internalize the ORA construct and thus learn how to create new knowledge and enhance their critical thinking skills. Furthermore students learn how to evaluate their work and their progress towards their personal goals from Assignment 0 (see Fig. 1).

At the end of the semester the students reflect on their learning in the 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 have really progressed in achieving their semester goals.

Best practices

Learning essays and assignments, that have the potential to add value to the learning of others become 'best practices' and are shared with the entire class. Often 'best practices' from former students of the course are also discussed in class or presented on the course website. This aspect of the presented approach enables collective learning; students learn from and about each other, get inspired and can build on others' work to develop new knowledge. A positive side effect is also an additional incentive to become author of a 'best practice' and the experience that an individual's work is taken seriously by others.

Project

The students are expected to validate a part of their answer to the Q4S through a project (Fig. 1). 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.

In this section we explained how the combination of scaffolding and customization of the course enhances the students' learning and leads to the creation of a diverse set of new knowledge. In order to make this beneficial for all students, the presented approach includes a collaborative part that fosters collaborative learning and provides the students with the opportunity to experience mass collaboration. This aspect is presented in the following section.

COLLECTIVE LEARNING THROUGH THE COLLABORATIVE ANSWER TO THE Q4S AND THE COLLABORATIVE LEARNING FRAMEWORK

Collective learning through the collaborative answer to the Q4S

The Collaborative Answer to the Q4S is collaboratively developed by all students through combining and refining their individual answers. It is an approach to combine collective learning and collaborative learning. Without a collaborative part, earlier efforts on infusing mass customization in courses such as the one presented in [19] resulted in a set of this diverse work from the students. Students had the opportunity to work on personal semester goals and concentrated on different topics. However, the integration of diverse expertise was missing. The diversity of the knowledge created in the customized part was not employed for collective learning. In order to be able to be innovative and create breakthrough designs, future engineers have to go one step further and analyze a variety of results in order to synthesize them and derive new knowledge. In the approach presented in this paper, this aspect is executed in the collaborative answer to the Q4S.

In ME6102 a wiki-style homepage is provided for the students to work together on the collaborative answer to the Q4S. Everybody is encouraged to contribute with the individual competencies and knowledge to generate a detailed and comprehensive answer to the Q4S. This is strongly related to mass collaboration and is a part of the course content.

In this exercise the students have the opportunity to learn several things. First, they learn from each other's knowledge, similar to best practices. Second, they learn with each other by collaborating on the overall fit and consistency of the document. Third, they learn about mass collaboration; they have the chance to experience the opportunities and also the challenges of mass collaboration. During this exercise, students develop the competency to contribute with their own strength and skills to a mass collaborative project. The learning approach addressed in this part is related to collective learning where the students have the possibility to learn from the work of others but are responsible for their own learning.

Setting up the Web-based collaborative learning framework

The collaborative learning framework is a web portal which is used as a central communication tool for all the members of the course. It allows students from various locations to work together and learn from each other even though they do not have the opportunity to attend in-class lectures. It also allows the course orchestrators to keep track of students' activities and progress in the course and helps in tailoring the course based on the individual needs.

The web-based collaborative learning framework is developed using the open source software application Drupal [31, 32]. It is a modular framework that allows fast development of community driven websites. The main Drupal application contains the basic functionality of user management, administration tools, blogs, etc. All other functionality is added using modules that can be downloaded separately from the Drupal website. Joomla or similar content management systems could also be used for the development of a similar community based website.

The key features of the web-based collaborative learning environment are as follows:

Online lecture material and videos: Each lecture in the course is videotaped and the videos are available on the web-based collaborative learning framework for the distance learning students to view. The in-class students also get the opportunity to revisit the online lecture material.

Students' profiles: Each student has a profile that contains their personal details, contact information, research projects in which they are involved, their expertise, and educational background. The profile page helps students to get to know their colleagues. This is a helpful tool particularly for the distance learning students who are not able to meet their classmates face-to-face.

My ME6102 on a page: In addition to the profile pages, each student also has a section on the website called 'My ME6102 on a page'. In this section, the students list their learning objectives and competencies for the course, how they have augmented their individual question for the semester and which aspects they would like to focus on in the collaborative answer. A sample 'ME6102 on a page' is provided in Fig. 3. The 'ME6102 on a page' exercise allows students to find team-mates for group projects, and other students interested in similar topics. This serves as a means for the students to partition the overall collaborative answer exercise into different aspects on their own. The students get an understanding of their role in the collaborative answer. They also get a feeling for how the contributions from different students will fit together in the collaborative answer.

Students' Assignments and Learning Essays: The students are required to upload all their assignments and learning essays to the website so that their fellow students (peers) can learn from them. This also allows the orchestrators to gauge the performance of students.

Ratings and comments on content by peers: All the content on the website can be rated on a scale of 1 to 10 with 1 being Poor and 10 being Outstanding. The students can rate their classmates' assignments, learning essays, project ideas, etc. Rating by peers is an important mechanism by which a lively interaction can be fostered between students, which helps increase their motivation throughout the course. In addition to the ratings, students can also provide comments to the content on the website.

Best practices: The orchestrators upload all the best practices to the website so that students can learn from their colleagues. Sharing of best practices facilitates collective learning. The desire to get best practices also increases the students' motivation to do well in the course.

Collaborative answer to Q4S: The collaborative answer to the question for the semester is an online hierarchical structure of web pages that allows users to create sections and subsections that can be edited by anyone in the class. The log of revisions to the sections is maintained. It is also possible to see each individual's contribution to the collaborative answer.

Student web-log (blog): Each student has a blog where they record their Assignment 0 semester goals and competencies. The students can regularly update their blogs with the progress on achievement or the change of goals.

Discussion forums: Discussion forums allow asynchronous communication between the students. They can share interesting findings and observa-

Name: Markus Rippel	**E-mail:** markus.rippel@gatech.edu
Personal Semester Goals: Learning Objectives and Competencies	
Learning Objectives: **1.** I want to gain a deeper understanding of the product realization process and realize its requirements for 2020. **2.** I want to learn what an open engineering system is and how to design engineering systems which are solutions to the problems of the future. **3.** I want to learn methods and tools which help the designer to cope with the challenges of 2020 by using the potential of globalization and mass collaboration. **4.** …	*Competencies:* 1. I want to gain the ability to apply Bloom's Taxonomy and ORA effectively, especially analyzing, synthesizing and evaluating. 2. I want to gain the ability to analyze and compare existing knowledge and to synthesize it to create new ideas which are outside the box and beyond existing boundaries. 3. I want to gain the ability to list, compare and asses my tasks and their priority in order to manage my time by creating an appropriate plan of action according to this judgment., etc.
Individual Answer to the Q4S	
My Augmented Q4S: Imagine that you are operating **engineering consultancy for** product creation enterprises 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) …	*My Definition of OES:* Open Engineering Systems are systems of **global** industrial products, services and/or processes that are **flexible**, readily adaptable to changes in a **global marketplace**, and open for continuous improvement using **mass collaboration and customer co-design.**
Key Aspects of My World of 2020: • Fast changing environment • Increasing complexity of technology • Increasing role of the individual in G 3.0 • Increasing demand for eco-friendly products	*Main Aspects of My Requirements List:* • Active IP Management of the company • Utilize mass collaboration in the product realization process • Integrate human-centered design • Integrate parametric design • Learning organization

Framework for My Business Plan:
Chapter 1 : Introduction to the Q4S
Chapter 2 : My Q4S
    Original and tweaked Q4S
    Justifications of changes
Chapter 3 : My World of 2020
    Drivers and Metrics
    Requirements List
Chapter 4 : My OES
    'old' and new definition
    Justification of Changes
Chapter 5 : My Q4S Company (core of Business plan)
    Organization (Structure, Environment, Culture, Recruitment)
    Tasks and goals
    IP management
    Open design method
    Human-centered parametric design
Chapter 6 : Validation
    Validation of Human-centered parametric design with project
Chapter 7 : Critical Evaluation of my Q4S
Chapter 8 : Learning	

Collaborative Answer to the Q4S	
My Contributions to the Collaborative Answer to Q4S • IP management • Learning Organization	*My Proposed Contributions* to the Collaborative Answer during the Rest of the Semester • IP management • Learning Organization
Project	
Project Title: *Human-centered parametric bicycle model*	*Aspects of the Business Plan that I Plan to Validate* • Integrate human-centered design • Integrate parametric design

Fig. 3. Example 'ME6102 on a Page'.

Fig. 4. A screenshot of the collaborative learning framework showing a student's profile and ME6102 on a page.

tions with their classmates. The discussion forums allow the distance learning students to interact with other in-class students. The conversations are archived for future reference.

Private messages: The website also allows private messages between individual students and between the orchestrators and the students.

An example of a customizable profile page is shown in Fig. 4. It also increases the students' motivation by providing personal identification with the project.

Information on the website is made available in a simple and adjustable structure. In Fig. 5, the section for the collaborative answer is shown. It is very flexible, meaning that every student can change the outline by adding, deleting, augmenting or renaming sections.

Collaborative answer to the Q4S in achieving collective learning—A discussion

In Spring 2008, a decentralized approach for developing the collaborative answer to the Q4S was adopted. However, in order to jump start the project, a starting outline was provided by the orchestrators to the students. After that, the development of the collaborative answer to the Q4S was entirely left to the students. No one was assigned any specific task.

To some extent the collaborative answer to the

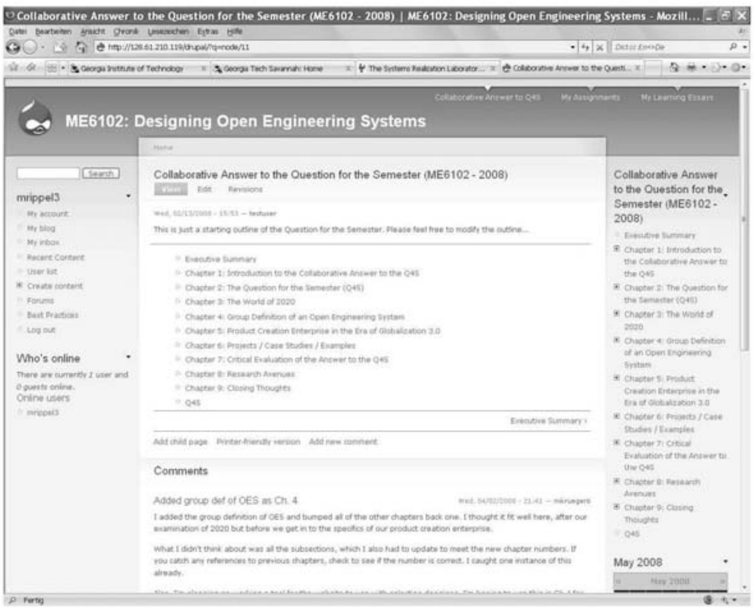

Fig. **5**. The collaborative answer to the question for the semester on the collaborative learning framework.

Q4S is similar to books that are written in a mass-collaborative manner [33]. The collaborative answer also had features similar to open source software development such as Linux, and mass collaborative product development such as the open source car (www.theoscarproject.org). Through this exercise, the students were able to experience and identify the nuances of mass collaborative product development.

Based on the use of the collaborative answer to the Q4S, the orchestrators realized that the key challenges in using such an approach to collective learning involve ensuring that: (a) everyone is actively involved in the project; (b) everyone contributes to the project; and (c) different participants build on the value added by others. The overall challenge is to ensure that collective learning is indeed taking place.

The orchestrators identified key factors for the success of such projects as follows: (a) the participation architecture; (b) the incentives provided to the students to contribute to the project; (c) the assessment mechanism used; and (d) the involvement of the orchestrators. By appropriately structuring these aspects, the orchestrators can increase the likelihood of the success of such projects for achieving collective learning. These aspects are discussed next.

The participation architecture of collaborative answer to Q4S

The participation architecture refers to the manner in which the participants in the project communicate and contribute to the project. It includes how the changes are handled, the rules, etc. The participation architecture has a significant effect on the outcome of the project. A well-aligned participation architecture may result in significant success, whereas a misaligned participation architecture may result in the failure of the entire project. In a modular project, such as, for example, Wikipedia, the participation architecture is very flat. Anyone can add to the project, and anyone can edit the project.

The participation architecture is particularly important for projects in which different contributions are interdependent. For example, in the case of collaborative answer to the Q4S, if one section of the collaborative answer is dependent on the other section, then the overall speed at which the project develops is slow as compared with a project where the contributions are independent of each other. The participation architecture used in the collaborative answer to the Q4S is also very open. Anyone could contribute to any section. The sections may be updated at any time.

There are some challenges associated with such open participation architecture in the Q4S. First, the students may not necessarily check the consistency of their changes with the rest of the collaborative answer. There is a possibility that many participants may wait for others to contribute before making their own contributions. On the other hand, others might try to be the first to add to a section to pretend contribution without having to integrate and combine knowledge. Further, students may be unwilling to edit the contributions made by their fellow students. This is different in a completely open mass collaborative project where the students do not know each other personally.

These challenges can be addressed by scaffolding the collaborative answer to the Q4S. The orchestrators can break the answer to the Q4S into various components so that the contributions are made systematically by first building the independent components (such as requirements list, world of 2030, etc.) followed by the dependent components. One of the students in the course suggested 'having a structure that differs from the one of the individual Q4S might provide more incentive to integrate individual contributions and thus could improve the quality of the collaborate project.'

The advantage of using a tightly controlled structure is that using consistency between sections can be enforced efficiently. On the other hand, the advantage of an open structure is that there is a greater possibility of getting diverse ideas from the combination of ideas from different students, thereby greater collective learning. Hence, there is a need to balance the open nature and the tightly controlled structure of answering the Q4S. Various other suggestions for modifying the participation architecture were offered by the students at the end of the course. One suggestion is to make different students responsible for different sections. In this approach the 'gardener' for each section encourages contributions from all participants, but is responsible for ensuring the consistency with other parts. This task could be limited to condensing the information contributed by participants and pointing out inconsistency or disconnects. This would make it easier for others to contribute since the students do not have to work through a pile of unstructured contributions before adding new ideas.

Role of incentives in collaborative answer to the Q4S

Incentives play a very important role in mass collaborative projects. In general, mass collaborative projects such as open source software development have various types of intrinsic and extrinsic motives. Intrinsic motivation refers to engagement in activities without external incentives whereas extrinsic motivation is driven by external factors like rewards, salary or coercion.

Lakhani and Wolf [34] analyzed different types of motivation in open-source projects and identified the external motivational factors in the form of extrinsic benefits (e.g., better jobs, career advancement) as the main drivers of effort. They also found that enjoyment-based intrinsic motivation is the strongest and most pervasive driver. Furthermore, intellectual stimulation and improving programming skills were identified as top motivators for project participation.

In the collaborative answer to the Q4S, the main incentives are personal learning interests (intrinsic), and grades (extrinsic). In this course, the grading incentive was provided by assigning a 10% grade to the collaborative answer. One of the key differences between this project and other mass collaborative projects is that in this course everyone was *required* to contribute but in projects such as Wikipedia only the participants, who have a natural interest, contribute to the project. The group size in the mass collaborative product development projects and collaborative answer to the Q4S is also different.

Based on the implementation of the collaborative Q4S the observation of the orchestrators was that the incentives are such that there is a tendency to contribute by adding sections to the Q4S but not ensuring that it is consistent. The students did not invest significant time to ensure that the entire Q4S is developed. It was apparent that students who invested more time in the collaborative Q4S started to develop intrinsic motivation through realizing the intellectual gain and the development of collaborative skills.

Hence, the contribution to the collaborative answer, the quality and, hence, the gain for all participants could possibly be improved by increasing the external incentive. This could lead to a higher intrinsic motivation once the project is started and contribution is visible from all students.

Role of assessment in the collaborative answer to the Q4S

The assessment of such collaborative projects is more difficult than assessing individual projects/tasks because there is no clear decomposition of tasks. Instead, the participants build on each others' work and the project grows in a step-wise manner. There are various ways in which assessment can be carried out in such collaborative learning projects: (a) self assessment; (b) mutual/peer assessment; and c) assessment by orchestrators.

In self assessment, the students perform the evaluation of their contributions themselves. They can use their learning objectives and competencies to discuss their learning. In peer assessment, the students can rate each others' performance by providing ratings and comments to their classmates' contributions. This process is similar to the peer assessment of publications in research journals. The use of peer assessment in a classroom setting is challenging because the students know each other and may be biased towards providing positive (or negative) reviews to their classmates. In the third approach, the orchestrators evaluate the performance of individual students' performances. This evaluation is based on the value that the students add to the entire group, and also the value that they derived from the collaborative exercise. The web based framework presented in this paper allows the orchestrators to track the contributions from the students. The value derived from the project is evaluated in terms of both content and the process of mass collaborative projects.

Assessment is inherently linked to incentives because the assessment process may provide incentives to contribute. It is observed that because the students feel that they are a part of the community, their motivations are higher when their classmates provide regular feedback to them. Hence, the key challenge is to align the assessment process with students' incentives [35].

Role of the orchestrators in the collaborative answer to the Q4S

The course orchestrators also have a significant role to play in the collective learning of the entire group. If the collaborative answer to the Q4S is left entirely open for students to contribute, the group may never get started. The orchestrators can play an active role in providing the direction to the collaborative project. For example, the orchestrators can regularly read the contributions and provide guidance to the group. The orchestrators can identify and recognize best practices that provide the students with necessary motivation to do better than their colleagues.

The orchestrators also play a critical role in jump starting the project by providing a starting structure (outline) and necessary scaffolding throughout the development of the project. The support is particularly important in the initial phases of the project. During the project, the orchestrators can ensure that necessary connectivity is maintained. Further the orchestrators can support the project by scaffolding the project so that students can systematically build the answer.

The value of collaborative answer to the Q4S

The presented approach combines traditional pedagogical approaches such as in-class lectures with collaborative learning approaches. In particular, the collective learning experience in the collaborative answer to the Q4S is new to most students. They are aware of some aspects of the mass collaborative concept from famous projects such as Linux, Wikipedia and Facebook, which stimulate their curiosity and increase motivation. Especially, working in these collaborative environments increases the depth of learning. Students have to explain, discuss, analyze, and synthesize their collective knowledge in order to create new ideas and knowledge. Another key aspect of the pedagogical approach presented in this paper is that students also learn about distributed and mass collaborative work. It was observed that this objective was fulfilled in the implementation in ME6102. According to one of the students:

> I learned that 'mass' collaboration even with a pretty small mass is very difficult, especially within a short timeframe. Although the collection of ideas and thoughts worked out pretty well, the step to the collaborative answer was not made entirely. The

problem is that the synthesis requires making a decision. One has to choose which source to take and which aspects from other authors to delete because they do not fit to the chosen solution. I learned that obviously nobody wants to delete the work of others in a group constellation like our class. Furthermore I realized that for many classmates, sometimes also for me, the motivation was too small to take the time to read all postings.

Excerpt from a student's learning essay

Recent developments in mass collaborative projects show significant potential of this concept. Industry and academia in future will increasingly try to use this outside knowledge. Being familiar with the mass collaborative approach, knowing the strengths and challenges and gaining the experience would be advantageous for the future employees and researchers. Furthermore, students educated with the presented approach learn how to contribute with their individual competencies to a greater project. This aspect is especially supported in the mass customized course setting where the students formulate their personal objectives and competencies and learn how to evaluate their own work and contribution.

CLOSING THOUGHTS

In this paper, an approach for educating engineers who are comfortable in making their mark in a world characterized by Globalization 3.0 is presented. The pedagogical approach consists of three main aspects—scaffolding, collective learning and mass customization of education. Scaffolding is achieved by providing a structure to the course that consists of lectures, assignments, learning essays, individual answer to the Q4S and project. Collective learning is achieved through the collaborative answer to the Q4S and by the use of best practices. Mass customization is achieved by allowing students to define their personal semester goals and providing flexibility in various aspects of the course such as lectures, assignments, projects and learning essays so that the students can achieve their individual goals while being a part of the group.

The pedagogical approach presented is well grounded in the theory of education (see the section on 'Educational Background and Instructional Techniques') [11–17, 19] and, in a unique way, combines several widely accepted instructional techniques that are used to act in concert in order to achieve the overall goal: fostering deep learning among students and enhancing the learning environment to facilitate this process. The course and the instruments used to implement it are based on the concept of constructive alignment [36, 37], i.e., everything from personal semester goals through content, learning activities, instructional techniques to delivering the content, and assessment are intertwined in a meaningful manner. In particular, students are guided through a number of activities that help them address and succeed at all the levels of intellectual behavior of Bloom's taxonomy [24].

The authors believe that the Assignment 0 is one of the important parts of the course. The orchestrators need to work with the students to help them define their learning objectives and competencies in the context of Bloom's taxonomy. Without a clear definition of the students' personal semester goals, it is difficult to mass-customize the course material. Getting the students to speculate about how design will be done in the future is another important aspect of the course. It allows students to think beyond the material presented in the course. This practice helps students reach the higher level competencies in the Bloom's taxonomy. The orchestrators should provide appropriate questions for the students to reflect on in their learning essays. The collective learning aspect is also an integral component of the approach presented in this paper. It is important to carefully design the structure of the collaborative answer to the Q4S so that the students gain maximum value out of the exercise, both in terms of the course material and the Globalization 3.0 environment in which they will be operating.

Through the implementation of the pedagogical approach presented in this paper, the orchestrators have identified various potential research opportunities and remaining research questions. Ideas to increase the participation through structure and incentives were discussed in the section on 'Collective Learning through the Collaborative Answer to the Q4S'. Further development of the approach could include the creation of an open source course software package that includes the content management system with the required add-ons and a suggested structure. Ideally, this allows the integration into existing course management systems of universities. One student even suggested the integration into Facebook, LinkedIn or similar social networks.

Other open questions include the following.

- How can the pedagogical approach incorporating mass customization and collective learning be applied to courses other then engineering design courses such as ME6102?
- What has to be changed to make it applicable to other courses?
- Can the collaborative answer be opened to the public and connect students in different courses at different universities independently?

The pedagogical approach presented in this paper is a step towards achieving Senge's vision of learning organizations [9]. The authors believe that the approach also has potential applications in an industrial environment. The following questions need to be addressed in future work.

- Can this approach be used by companies for interdisciplinary projects and in order to motivate employees?

- Can companies apply this approach to create new knowledge and breakthroughs in mass collaborative projects within or also across the company's borders?

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