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An integrative teaching and learning concept for management and engineering

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The Open Design education approach - an integrative teaching and learning concept for management and engineering

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***Abstract*— Construction Management and Engineering students need to acquire managing skills for solving real-world problems that are complex, rarely straightforward and lack 'one right answer'. For this, they need to become 'open designers', capable to be reflective, integrative and creative in- and on action with dynamic and new situations. In this paper, the so-called Open Design Learning Circle (ODLC) will be proposed as an innovative educational concept in which engineering-, management- and pedagogic sciences are integrated. Within this concept the students 'dialogue' with: 1) an objective open glass box model covering engineering products and management processes (outer) and, 2) their subjective open human threefold, reflecting their personal learning (inner). The integration of both human and model dialogues is essential for the emergence of new knowledge and creative insights for open designs, which is essentially distinct from more traditional learning concepts. To enable this emergence, a self-chosen system of interest is the 'experiential vehicle' that forms the basis for a self-created textbook and model. Thereby, the ODLC forms the fundamental basis for creating 'open and persistent learners'. In this paper, it also will be shown how the ODLC can be operationalized into a learning cycle and how it has been implemented in an example course on systems engineering management within the MSc Construction Management & Engineering curriculum at the TU Delft. Finally, some preliminary student findings and next steps for further research are discussed.**

Keywords*— *Construction Management and Engineering; Experiential Learning; Co-reflecting, co-creating and co-sensing, Problem Solving; Integrative Education; Open Design Learning Circle/ Cycle, Management Process/Engineering Product/Learning Person; System of Interest.

I. INTRODUCTION

The scientific field of Construction Management and Engineering (CME) involves the application of engineering skills and scientific knowledge to asset and project management of infrastructures and buildings. While engineering focuses on design and construction of physical assets (bridges, tunnels, buildings, offshore facilities, etc.), managing is concerned with overseeing the actual construction process and related (human) activities (planning, budgeting, organizing, information, risk & safety etc.). CME often represents a blend of both disciplines, integrating engineering service-life design and management of projects and asset operation. CME is educated at several universities all over the world.

The Dutch 4TU Master in Construction Management and Engineering (MSc CME) anticipates the growing need in the construction industry for coping with future solutions in a multi-disciplinary setting. The students in this program, who will work in this multi-disciplinary setting, need not only develop their engineering, problem-solving skills, but also to acquire managing skills in how to solve problems in 'real-world' environments which are complex, rarely straightforward and lack 'one right answer'. In the curriculum, typical courses are offered to, for example, cope with engineering asset management, systems engineering management and/or information systems topics. For this, they also need skills to assess the consequences for the entire construction process and its organization. CME students, therefore, require education on the edge of managing and engineering geared towards preparing them for dealing with the actual multi-faceted problems in their profession and preparing them for generating new solutions for future problems. Therefore, students who will become CME practitioners will need to have problem-solving skills rather than (only) problem-oriented skills both for the engineering and the management part of the problems. Finally, this all results in delivering unique CME masters with a so-called ζ-profile, integrating β- and γ-skills [1] in a proper and individually balanced manner.

For research in this interdisciplinary construction engineering and management field, a clear distinction is

[1] In the Netherlands, Beta's (β) graduate from the technical engineering science universities (e.g. TU Delft) and Gamma's (γ) graduate from the social science universities (e.g. Erasmus University Rotterdam).

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made between: 1) managing and related processes, and 2) engineering and related products. For this CME research, the research approach for the management processes needs to be congruent with the engineering products (design) approach.

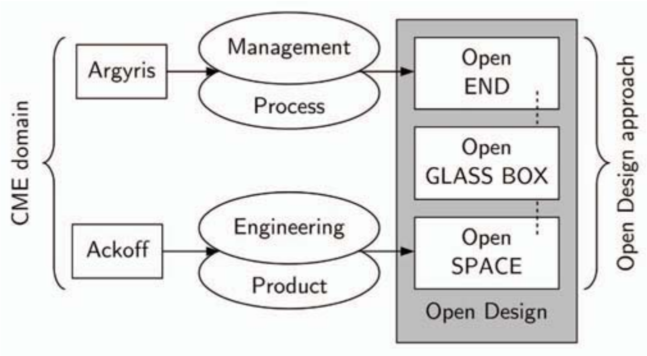

Fig. 1. The Open Design integrative research approach.

Figure 1 shows such an integrative and congruous research concept called the 'Open Design' approach. It shows how the concept of the notion of an 'open ended' process [1] is used as a model for management and its related processes. Here, the solutions are multiple rather than unique and are dependent on the chosen boundary conditions. The concept of the notion of an 'open space' [2] is used as a model for engineering (design) of products. Here, the solutions are derived from an integral systems and multi-stakeholder oriented approach where solutions are dependent on the optimization constraints. The notion of an 'open glass box'[2] modelling approach is used as a common thread to link the congruent notions of the open-ended process and open space engineering product design. Here, the linked solutions are quantitative, objective and model- and/or simulation-based so that the black-box character of the integrated multifaceted problem has been removed and clarified, resulting in Open Designs. This research concept and its application have been extensively described further in [3].

It is important to note three major characteristics of this Open Design research approach: 1) both engineering and management are considered to focus on problem-solving (vs. problem-oriented and/or empirical), i. e., engineering management systems improvement and synthesis; 2) the acknowledgment that both engineering and management have to deal with real-life (physical) situations that limit the amount of degrees of freedom, i. e. reality provides feedback on human interventions to improve situations such that feasibility is of major importance; and 3) integrated management and engineering problems will have to be solved quantitatively modelled in order to recommend objective CME results (e.g., dynamic programming; systems dynamics, combinatorial simulation, structured expert judgment, artificial intelligence, etc.).

II. GOAL

The Open Design research approach has proven its usefulness for research on construction management and engineering [3], however, its potential for also supporting CME education has not been properly addressed yet. Since the Open Design research approach is based on problem-solving related to real-life CME situations, we need a congruent educational approach. In other words, an educational concept where engineering products, management processes and a learning person are integrated so that new insights and future solutions will emerge. In this paper, the so-called Open Design Learning Circle (ODLC) will be proposed as such an innovative educational concept in which elements of engineering, management and (societal) pedagogic sciences are integrated. Moreover, it will be shown how this can be operationalized by means of a weekly learning cycle integrating all ODLC aspects implemented in an example course on systems engineering management, including the weekly student and teacher course interactions. Finally, some preliminary findings, conclusions and further research are discussed.

III. THE OPEN DESIGN LEARNING CIRCLE (ODLC)

Many critics of management education argue that graduates are not prepared to respond to work situations in ways for which employers are calling [4]. Management education has been regularly criticized on the grounds that graduates are not equipped with appropriate problem-solving skills. In other words, they are too alienated from the managerial workplace [5,6]. A weakness perceived by the industry is that business management schools currently focus more on problem-orientation than on problem-solving, creating novel approaches to problem solution and risk-taking [7]. On the other hand, traditional engineering schools are mostly rigidly organized in disciplinary silos and produce disciplinary programs. Engineering students will therefore often be trained in mono-disciplinary unique problem-solving and are not familiar with a multi-faceted systems orientation approach [8].

We, therefore, need an educational approach that: 1) integrates management processes and engineering products in a congruous manner, 2) focuses on the development of solutions to engineering management system problems, 3) acknowledge the importance of incorporating feedback from real experiences, 4) ensure that the engineering and management knowledge and concepts can be transformed into a situational, sensible and personal system of interest, and 5) insights and solutions can emerge in reflective processes between the person's inner and the outer (product and process).

For this, we now first describe different elements of existing learning and developing concepts that can be used as an educational approach for enabling real-world knowledge and insight creation by engagement of students.

Knowledge/ insight creation and problem-solving

Both Experiential and Situated Learning Theories have been widely used in management learning research and practice for over 50 years [9, 10]. Experiential learning is the process of learning through experience, and is more specifically defined as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" [11]. Situated learning is a theory on how individuals acquire professional skills, extending research on apprenticeship into how legitimate peripheral participation leads to membership in a community of practice. Situated learning takes as its focus the relationship between learning and the societal context in which it occurs [12].

[2] As opposed to a 'closed black-box'.

Both of these learning perspectives can be contrasted with alternative views of learning. For instance, rather than defining 'learning' as the acquisition of propositional knowledge, learning is considered to emerge from certain forms of social co-participation and transform from certain forms of experiential co-creation. Rather than asking what kinds of cognitive processes and concepts are involved, these learning perspectives ask what kinds of social- and experience-world engagements provide the proper context for learning to take place. Note that both experiential and situated learning are distinct from rote or didactic learning, in which the learner plays a comparatively passive role. In parallel, experiential and situated learning is similar to constructivist learning as didactic learning is similar to instructivist learning.

Moreover, we acknowledge that, during experiential and situated learning, knowledge and solutions can emerge in a reflective process as Schön [13] describes. Schön's design method states that via inner engagement new designs emerge via the "system talks back" principle[3], i. e. transforming observations into intuitions and judgments about the present object and process state and decisions about the future, based on how design is taught and learned. Moreover, we recognize that these co-reflective processes form a basic learning condition to initiate new insights from co-sensing towards co-creating as described in the Theory-U, a theory of learning and management, in which development of new insights, problem-solving, change and innovation are essential [16,17]. Within these theories, the main elements are about *opening* up, dealing with and intentionally (re)integrating cognitive intelligence of the *mind*, the social emotion of the *heart*, and the practical experience of the *will*: the human threefold.

Finally, the individual learning processes of students, in our case of 21 plus years old, should be thoroughly taken into account. Here the authors again start from the previously mentioned human threefold (mind/heart/will), following other (social) pedagogists [18,19,20]. Especially, in the case of our MSc students, we are convinced to undertake a top-down learning approach, in which we start from the cognitive mind process of *thinking* via an individual connected system for *engaging* towards self-created deliverables by *experiencing* and *transforming* the new insights into self-created learning deliverables by *linking* the mind, heart and will. In this internal and external process, teachers are assisting the students in the process of co-sensing, co-creating, and co-reflecting accordingly. Other educational researchers e.g., [21,22,23,24,25] also acknowledge and/or use this learning view and starting points, but from other perspectives, backgrounds and/or different student ages (primary, secondary, and higher education). Last but not least, it should be noted that the typical CME context is rather abstract and conceptual at the age of 21 plus years old. This means that integration of thinking, engaging and experiencing would have to bring this context 'alive' so that it will 'become' intrinsic and 'takes root' motivated and forever.

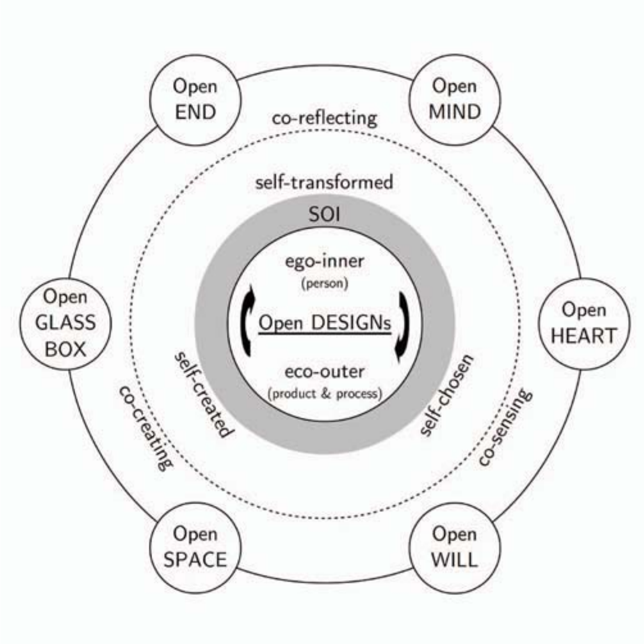

Fig. 2. The Open Design Learning Circle (ODLC).

From the above learning and developing starting points we developed a new educational concept, called the Open Design Learning Circle, see Fig. 2. This concept is a framework that serves as the core instrument for developing, executing and/or improving several CME courses[4] at TU Delft. From the Open Design research approach, it takes the notions of an Open space, Open end, and Open glass box (see their meanings in the Introduction). From the educational learning and development concepts, it takes the notions of the threefold Open mind, Open heart and Open will. Here, Open mind stands for a cognitive approach in which (existing) concepts and knowledge are retrieved and/or generated by thinking/analyzing; Open heart stands for a connected approach in which (existing) concepts and knowledge are transformed into an individual engagement by feeling/sensing; Open will stands for an experiential approach in which (new) concepts and knowledge are created and/or modelled by doing/working. The internalization of new insights and knowledge generation is done by a top-down and interactive integration of these three domains.

At the center of the Open Design learning circle are what we called the 'Open designs' that emerge in a dialogue between the inner ego (personal learning development) and outer eco (engineering product and management process). To enable this, a self-chosen system of interest (SOI) is the 'experiential vehicle' that forms the basis for a self-created textbook and/or model in which self-transformed concepts and knowledge are assimilated with the person's actual world and interests. The need for an intrinsic motivation as a fundamental basis for persistent learning is also shared by others in the field of primary, secondary, and higher education, see [20,26,27,28].

[3] This phenomenological diagnosis of the present state principle is also known as Goethean sciences-techniques [14] or [15].

[4] The following courses of our research & education group are/will be ODLC based: CIE4381/CME4300 Engineering Asset Mngt.; CIE4481/CME4400 Systems Eng. Mngt.; CIE4120/CME4100 Information Systems; CME 2210 Open Design & Construction Mngt; CIE 4391 Quantitative Asset Modelling.

The link between the outermost circle notions of an Open space, Open end, Open glass box, Open mind, Open heart, and Open will and between the innermost circle of the Open designs is established through the mechanisms of co-sensing, co-creating and co-reflecting, as depicted by the dotted circle. This circle resembles the multiple interactions between the student's inner self and the outer engineering management system, in dialogue supported by the teacher. In other words, from the left-hand part of the ODLC, the system 'dialogues' via an objective and quantitative open glass box model covering products and processes. Conversely, from the right-hand part of the ODLC, the human 'dialogues' via his/her subjective and qualitative inner person. The integration of both human and model dialogues is essential for the emergence of new knowledge and creative insights for Open designs. In the next section, we describe the Open Design learning cycle, i. e. how the Open Design learning circle can be operationalized by means of a weekly cycle integrating all aspects of this learning circle.

IV. ODLC IMPLEMENTATION

To implement the Open Design Learning Circle, a repetitive session schedule which is clear to the students has been developed. This is the so-called Open Design learning cycle which is essential for the integrative processing of the concepts resulting in individual learning deliverables, see Fig. 3. It is a broad outline which can be tweaked to better fit the practical and/or typical characteristics of other engineering & management courses. In this section, the cycle will be further elaborated for the MSc course on Systems Engineering Management (TUD-CIE4481). It is a ten weeks course in which there are seven weeks reserved for interactive sessions (two sessions of at least two hours per week).

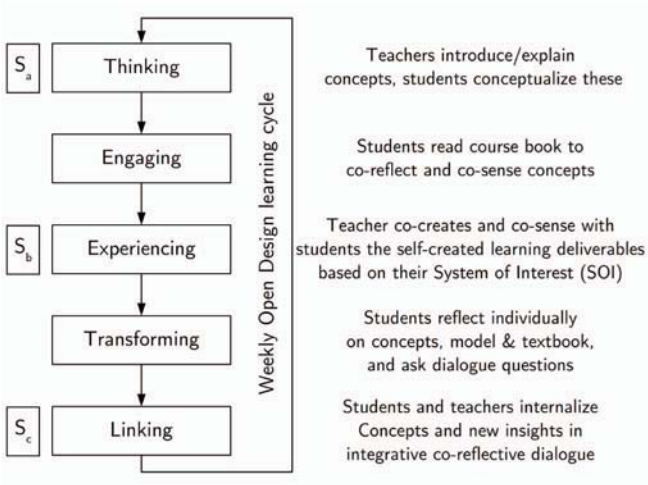

Fig. 3. The weekly Open Design learning cycle.

Every first session of the week (Sa) the teachers introduce and explain the new concepts for that week. The information will be shared in a rather traditional format of a presentation (sending information, max. 45 min). This allows students first of all to think about and conceptualize these concepts.

Between the first and the second session (Sb), students are required to further familiarize themselves with the new concepts. For guiding the students, a concise reader is used indicating relevant chapters in existing course books (e.g. the systems engineering books of [29,30]). These books primarily serve as a reference book enabling the students to navigate through the necessary theories with their self-chosen System of Interest (SOI) in the back of their mind. This is where students co-reflect and co-sense concepts and get engaged with these. It is important to note that they can do so without already entirely connecting the new concepts.

The second session (Sb) is meant for connecting the new concepts to their self-chosen SOI. In these sessions, the teachers co-create and co-sense with students the self-created learning deliverables based on their SOI. All the concepts are the starting points for the individual 'colorization' of their self-created textbooks. The majority of concepts can be directly linked to the self-developed (computer) open glass box models that depict open space and open-ended solutions. In this process, the students co-reflect with both the teacher and their SOI. An important aspect of these practical sessions is that the model 'talks back' to the students; they experience how reality limits their open designs (solutions and new insights) that are geared towards different optimization criteria. Finally, the students process these open designs together with the more qualitative concepts into their self-created textbooks.

Between the second session (Sb) and the first session of the next week (Sc), students can reflect individually on the concepts, their model and textbook and send in dialogue questions on these open designs and their relation with their SOI. This is where they reflect on action and transform insights into their (intermediate) learning deliverables.

The first part of the session of the new week (Sc) is where students and teachers internalize concepts and new insights in an interactive dialogue session (co-reflection of max. 45 minutes). This is the moment where students link the cognitive-mind, engaged-heart, and experienced-will personal learning processes securing the deliverables into their final self-created learning deliverables. The second part of the session of the new week equals the start of the previous week (Sa) as described above (sending new information, max. 45 min).

Each weekly cycle results in additions to both the self-created textbook and the self-developed model. At the end of the 7 week course, these learning deliverables are partially completed. At this moment, the students are presenting these to the teachers who assess their individual learning outcomes. The teachers also provide feedback for the final completion of their learning deliverables in week 10. The final grade is based upon the individual assessment in week 7 and their final deliverable in week 10. So, in our view and in line with the ODLC principles, it is adequate to evaluate the learning outcomes in this manner instead of having a traditional exam. Note that the number of students per course might impact this assessment process. Currently, this cycle is working for a group of approximately 20-30 students.

V. PRELIMINARY STUDENT FINDINGS

As mentioned in the previous section, we are currently applying the ODLC to an MSc course on Systems Engineering Management (TUD-CIE4481). Some of the essential ODLC elements have already been worked into other courses, e.g. TUD-CIE4120/CME4100 Information Systems and TUD-CME 2210 Open Design & Construction Management. However, the entire ODLC has only been embedded within one course yet.

At the moment of writing this paper, the course is roughly halfway. In this section, we will summarize some preliminary findings based on student's feedback that we received by means of both an anonymous questionnaire and by personal interviews.

Most students appreciate the provided rudimentary reader that acts as a guide for introducing the new concepts. They acknowledge that without this reader they would struggle in *thinking* about and conceptualizing the theory and concepts from the references course books.

The freedom to choose their own SOI is appreciated by most students as it incites *engagement* so that engineering-driven students note that the course concepts even could be applied to their specific civil engineering domain. When asked for the motivation for choosing their particular SOI we notice that most of them indeed base their choice on a true 'connect' with their SOI: e.g., connected to a future international internship on power dams in Vietnam or connected to a new transportation link between the North and South of Amsterdam. Figure 4 shows an example of the Vietnam group's SOI.

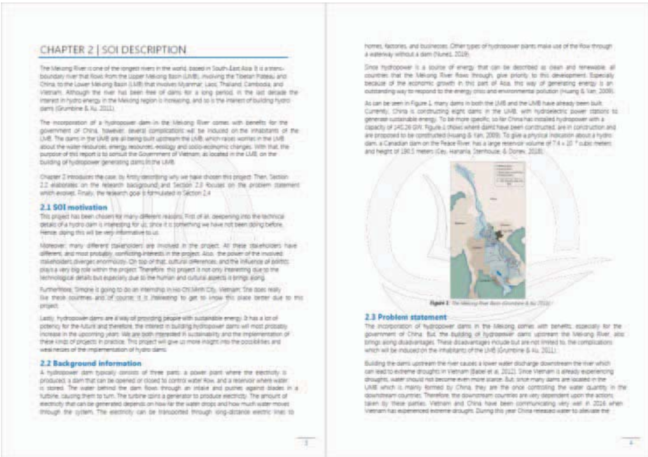

Fig. 4. An example of the Vietnam group's SOI as part of a self-created textbook.

Most students acknowledge that by working on a model that represents a real-life situation they *experience* and *learn* more than by just participating in a traditional lecture. We attribute this partly to the objective and quantitative nature of these models that limit the degrees of freedom and allows that the model 'dialogues' with the student.

They also acknowledge that the combo of: 1) the practical experience and simulation session, where they develop and work with the model, and, 2) the dialogue session, where they reflect with teachers on their posed questions (*transforming*), helps in understanding and *linking* new concepts.

Students appreciate that they can immediately apply new concepts to the model of their SOI and get a better understanding of these new concepts instead of having to memorize concepts for taking a 'classical' exam.

Quite a number of students state that this way of learning is more intense from the start throughout the course period instead of 'consuming' along the course and peaking at the end. This is due to the use of a self-to-be-developed computer model and the related self-to-be-created textbook which is significantly new to them. It is also due to the requirement of using a real-life SOI from which they have to extract the relevant qualitative (used in the self-created textbook) and quantitative data (used in the computer model). Figure 5 shows both an example of the table of contents of a self-created textbook and a snapshot of the computer model of the Vietnam group.

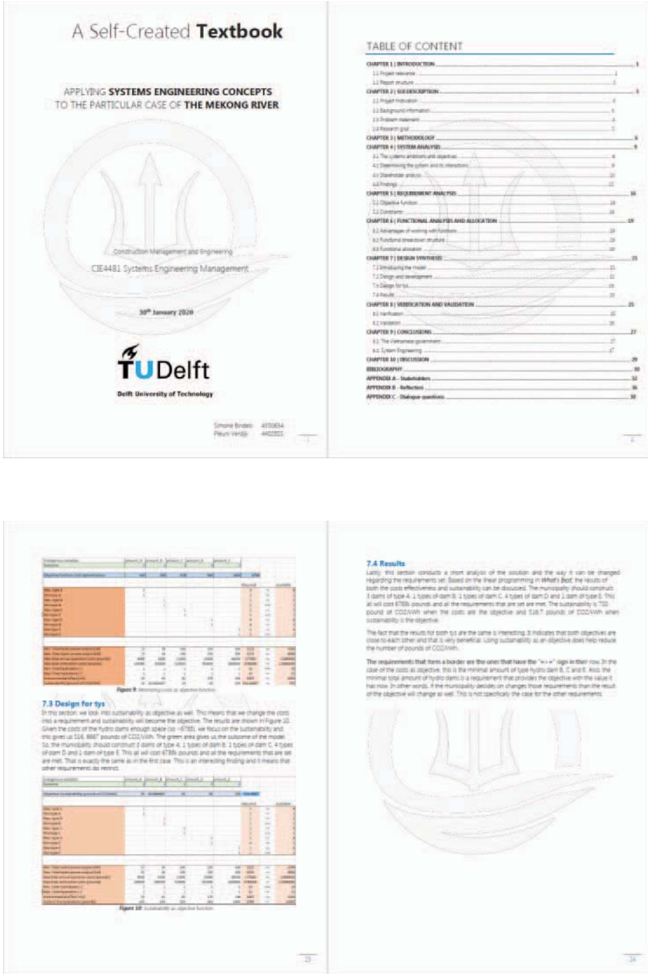

Fig. 5. An example of the content of a self-created textbook, incl. the glass-box computer model[5] results of the Vietnam group

The use of computer models for modeling the design management process is completely new to the students. We notice a curiosity on how to properly model such a process in relation to their own SOI. The first weeks are predominantly spent on becoming familiar with this new modeling technique. However, the aim of this course is to provide students with a framework to which they can apply a large number of concepts, not to teach students how to create elaborate design/decision models (this will be the learning goal of TUD-CIE4391 Quantitative Asset Modelling).

We will also evaluate the course at the end of the 10 week period in order to gain insight into the required changes to improve the course. Future courses to which we will apply the ODLC will be evaluated at the start, during and directly/amply after the course has ended. Moreover, we believe that students should also be evaluated after they have graduated when being a CME industrial or researcher.

[5] Here a linear programming operations research model has been used for the design space optimization.

VI. Conclusions and Next Steps

A. Conclusions

The compound reflective, creative, engaged and process-product modeling based Open Design Learning Circle (ODLC) proposed in this work is innovative and is expected to better prepare MSc students for their career in the construction management and engineering industry. It enables the students to effectively learn the rather abstract and conceptual theories at the age of about 21 plus years old. It opens design solutions for multi-disciplinary engineering management systems via a quantitative glass box modelling approach combining process and product. It increases learning motivation by connecting the learning deliverables to an individual system of interest. It is expected to enhance their future problem-solving capabilities for new knowledge and insights that emerge in a dialogue between the inner ego (personal learning development) and outer eco (engineering product and management process). It helps in creating 'open learners' capable to be reflective, sensible and creative in- and on action with dynamic and new situations. Finally, the ODLC forms the fundamental basis for creating 'open, integrative and persistent learners'.

B. Next steps

Future research will focus on determining the effect of this type of education. For this, a five-step evaluation is foreseen, i.e. at the kick-off of the course, at mid-term, just at the end of the course, after graduation, and last but not least after the first three years of their professional career. With this evaluation,[6] we believe to get insights on how the ODLC approach will 'continuously' be carried on. Another point of our interest is to research whether typical international educational cultures/backgrounds will have an influence on the adaptation of the ODLC. We will test this impact within the rather international CME population at TU Delft. Concurrently, we would like the ODLC to become part of an international education network so that we can learn from and improve it from different perspectives.

Furthermore, the assessment process within the ODLC will have to be adjusted to accommodate courses having larger numbers of students. Especially, the individual assessment on the learning outcomes might include an open self-created textbook exam where students individually have to answer questions related to their group's learning deliverables.

The ODLC approach described in this paper also relates to the MSc graduation project of CME students. Students graduating on research themes where they need to solve real-world problems can also use this Open Design approach. Further research will focus on how this approach relates to MSc graduation processes.

Finally, the approach described in this paper aims to enhance the education of CME students and focuses on educating managerial skills with the engineering domain. However, we propose that education which is less focused on the managerial skills could also benefit from this approach whereby the use of an SOI and self-created textbook are again pivotal for creating 'open learners' instead of 'closed specialists'.

[6] For this survey we will make use of a constructive alignment approach in which we connect Learning objectives with Evaluation criteria, using Bloom's taxonomy. The goal is to determine whether higher levels of cognition have been achieved and whether they have also been achieved persistently. Currently, this evaluation is under construction.

VII. Final remark

Finally, the authors would like to remark the following. This integrative ODLC approach is unique in itself and is distinct from typical engineering education concepts such as for example, Case-based learning (CBL), Problem-based learning (PBL) and the Conceiving, Designing, Implementing and Operating (CDIO) framework, etc.

CBL is an established approach used across disciplines where students apply their knowledge to real-world scenarios, promoting higher levels of cognition (see Bloom's Taxonomy). In CBL classrooms, students typically work in groups on predefined and/or given case studies. In contrast, the ODLC approach incorporates the use of a self-chosen 'learning vehicle' that is their individual System of Interest (SOI). Based on this engaged SOI, the students self-transform existing concepts into their self-created textbooks and self-developed models striving for a more intrinsic learning motivation to internalize knowledge and insights that last longer.

PBL is a student-centered pedagogy in which students learn about a subject through the experience of solving a problem found in trigger material. The PBL process does not focus on problem-solving with a defined solution, but it allows for the development of other desirable skills and attributes. This includes knowledge acquisition, enhanced group collaboration and communication. The educational framework CDIO is partly PBL-based and stresses engineering fundamentals set in the context of Conceiving, Designing, Implementing and Operating real-world systems and products. This approach also uses active learning tools, such as group projects and cases, to better equip engineering students with technical knowledge as well as communication and professional skills.

The major differences between the CDIO/PBL educational approach are that the ODLC does incorporate solving of both an open-ended and an open-spaced problem while integrating engineering products and management processes. Apart from all the aforementioned differences, the essential distinction of the ODLC is that it explicitly integrates the development process of knowledge and insight creation by a person, seen as a human threefold.

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