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Enhancing an Integrative Course in Industrial Engineering and Management via Realistic Socio-technical Problems and Serious Game Development

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Abstract. This is a position paper. It discusses specific educational issues encountered during the Systems Engineering Design course at the Industrial Engineering & Management master program at the University of Groningen. It explains first the concept of an integrative course, an innovation that was applied first in this master program. It explains the causes and effects of two observed educational shortcomings of this course, and it links these to the extant literature. Finally, the paper proposes two ideas to address these shortcomings.

1 Introduction and Background

According to the current standards on engineering education[1], the courses in an engineering study program can be classified either as lecture-centric (LC), problem-based (PB or inquiry- based), project-assisted (PA), or project-centric (PC sometimes, these courses are named capstone courses). In the Industrial Engineering & Management (IEM) study program at the University of Groningen (RUG, in the Netherlands), an innovative learning paradigm has been developed and applied in the last decade: the integrative course. This kind of course is one that is placed at the end of the curriculum schedule, and requires the application of knowledge and skills learnt from the majority of the previous courses. The integrative courses are meant to apply both paradigms of problem-based learning and project-centric learning. This concept may sound similar to the capstone course[10].

Currently, at IEM, there is an accumulated experience of teaching integrative courses over the past 8 years, and there has been confirmation that the outcomes of these courses are the desired ones. The first source of confirmation has been the short-term and long-term feedback given by the graduates and alumni from the last decade. The second source was the industry, and the third source was the formal accreditation reports of the IEM program, revealing an increase in the quality of the master theses produced in the last years.

Despite the apparent success of the integrative courses revealed by these sources, the teachers who are involved in their development are aware of two

major shortcomings that reduce the effectiveness of teaching in the integrative manner. The extant literature[6] and exchange of experience (via personal channels) on the subject show that these shortcomings are not unique at RUG. The first shortcoming is the lack of realism and veracity of the “problem” that is to be solved by the designs developed during the integrative study. The second shortcoming is the lack of cognitive engagement between the teams and individual students who are doing the designs for the coursework, leading to a fragmented project development, and also a lack of communication and alignment in the integrative process. Later in this paper, the authors propose two ways to mitigate these shortcomings.

In the Netherlands, the higher education in engineering is provided by some of the existing public universities. In addition to these, there are a few dozen universities of applied sciences (UAS) and offering bachelor and more recently master level programs in various engineering disciplines.

During the 1990s, two change tendencies emerged in Dutch universities. The first change was driven by the industry, which asked more vocally for engineering students with skills like team work, context and problem complexity understanding, the ability to diagnose complex problems, communicate the findings, and the preparedness to coordinate solution efforts. At its core, this request challenged the old style of “chalk and talk” (i.e. LC) teaching. The universities responded in various ways, one being by applying PB learning, and another by inviting more and more professionals as guest lecturers. It was quickly learned later that PB learning is not the single or even the best solution for engineering.

The second change was to respond to the demand of the industry for a more multi-disciplinary kind of graduate. The response was a new type of engineering study program, namely the IEM. These master degrees are supported in each of these universities by a similar bachelor study program in IEM. Students who earn a bachelor degree in Industrial Engineering from an UAS can follow a special adaptation coursework for half a year and then start one of these master studies in IEM.

These IEM programs appeared exactly when PC and PB learning started to be applied in various engineering programs universities in the world. The disciplines that can be taught in PB style are those where knowledge is rather encyclopedic and less hierarchical (that is, the order in which the concepts are learned is not so important). The emphasis in these courses is to investigate a “situation/problem”, and find its causes (diagnostic). This is similar to the initial application of problem-based learning in medicine[11], and students learn and put together the pieces of knowledge along the way in finding the causes of the investigated “problem” (i.e. finding a diagnostic for it).

For those disciplines where knowledge is strictly hierarchical, the style of teaching is either PA or PC. The emphasis in PA courses is on analysis. The “problem/opportunity” that triggers the design is given by the teacher, and its causes and diagnosis are clearly established beforehand. The students have to analyse and specify requirements for a future design.

The disciplines taught in PC style, like for example software project management and control systems design (for robotics), have a strong emphasis on the design itself - the problem, stakeholders, and the requirements are mostly given beforehand by the teacher. Typically, project teams are smaller, of 3-5 students, each having a small portion of the design to tackle. Design of different teams are sometimes integrated into bigger designs, spurring collaboration between teams. Periodic presentations of the teams help that knowledge and acquired skills (and again, mistakes) are shared and discussed.

2 The integrative course and its shortcomings

At RUG, the master IEM program is ending with courses that apply an integrative approach. The emphasis is on technical integration, but both courses (the course in Systems Engineering Design and the course in Sustainable Engineering) have still a strong managerial/economic-related part.

In the integrative courses, all the learning styles (LC, PB, PA, and PC) are applied. There are plenary lectures, which present mostly examples of problems, stakeholders, requirements and design solutions. The “problem” has to be found/defined/invented by the students - with teacher’s assistance. Then, students have to analyze specify the requirements of a complex and multi-disciplinary system, and finally develop a conceptual design that meets the requirements and can stand a formal design assessment - an evaluation phase that is also performed by the students. Finally, the teachers role is that of the “buyers” of the design, who are involved in the design in iterative stages of its development, revealing its shortcomings, gaps, and inconsistencies.

The course Systems Engineering Design is the “oldest” integrative course in the IEM master program at RUG. Students are organized in teams of 3-4 students, and teams are organized in “triads” (three teams) of 10-13 students each. Each triad has a separate student who plays the role of system integrator. The tasks of the project are to define first - separately for each triad - a specific multi-disciplinary problem (which has to be more or less realistic), and explore the “stakeholders’ ” wishes. Next, the teams have to analyse and specify the requirements of a system that addresses the effects of the problem - each team in the triad specializes in a specific set of requirements. Finally, the system has to be designed in terms of a context-placed operational architecture, comprising a functional architecture described in IDEF0 and a generic physical architecture with alternatives for components and interfaces. The final deliverable is a dossier that is supposed to participate in a Request for Proposals (RfP) for such a system. The project is quite equivalent (albeit much shorter in time and smaller in scope) to the pre-inception phase[2] in a system development process.

The operational architecture has to be built by using a systems engineering CAD system (COREtm9 from the Vitech Corp.), which incorporates also requirements engineering tools. This CAD system allows for collaborative design and the integration of separate structures/interactions of functions and components that were designed by different teams. A recent example of system de-

signed was a bio-gas producing and storage infrastructure, which was supposed to replace/upgrade an existing infrastructure for fossil gas in a clearly delimited region. Because this course runs in parallel with the Sustainable Systems course, many problems are related to environmental issues, alternative fuels, and novel energy systems.

The students are encouraged to view this course as a “serious game”, where they compete to “sell” their design to the issuers of the RfP (see presentation[12]), and there is a constant competition for the best team and best triad. Moreover, the teachers (as a separate team) are developing each year a system in parallel with the students, sometimes as part of a triad with two other student teams. If a student team delivers a better project than the teachers, who get always a mark 9 (on a scale from 5 to 10), that student team gets the maximum mark. Each year, one or even two student teams manage to “beat” the teachers’ team.

This course is popular with other students than the IEM master program, for whom the course is compulsory. Each year, 15-20% of students are taking this course as elective, and they are coming from master programs like Computing Science, Energy and Environmental Science, Chemical Engineering, Econometrics, and even Law. They bring even more disciplinary knowledge and skills into the triads, and also ways of thinking that are new for the IEM students and even the teachers. The course is highly sought by exchange students also, who are studying at RUG only for a semester. However, there are also shortcomings.

Problem-based learning assumes that the problem is real, existing in a real context. In PB courses in medicine for example, the students are given a real patient case, which they have to investigate and diagnose. In PB courses in engineering, the students go into the field (typically a company) and are given or identifying a real problem. However, due to time and resource limitations, courses that have a design project at their core, hardly can cope with overloading the coursework with a diagnostic phase. Another typical issue is that teachers that are teaching in PC style, have limited experience with the PB approach. The net result is that in PC course that starts with a “problem” that is made up, typically by the teachers, who try to communicate its details as well as they can to the students. However, the problem “exists” only in the mind of the teachers, and many times, students do not grasp or have a really good understanding what the problem really is. The single way to figure out, is to continually “interview” the teachers about the problem, but many times this can lead to even more confusion. The net effect is that students are losing interest in the problem and in the project, going out from the “immersion”, “make-believe”, and “flow” state that make them feel like in an engaging game.

A simple solution (applied currently in the course Systems Engineering Design) is to let the students define the problem/opportunity themselves (with some teacher feedback). They have to describe it in a scenario-like narrative, and expand the details as they go with the design. However, this approach leads to other undesired effects. The problem becomes part of the design itself, and in order to have an elegant and technologically interesting design, the problem is changed in ways that bend reality. Especially the quantitative aspect of the

problems are suffering, and this can lead to problems that do not have a holding in physical reality, because the assumptions made lead to the violation of the laws of physics. The net effect is that students realize the lack realism of their problem at some moment, and again, they lose interest in the project overall. If they remain immersed and that happens many times, this creates an even more dangerous learning effect, because the students may remain convinced that this kind of unrealistic problems and designs exist in reality. If the students are brought back to reality during the final presentation or the previous feedback sessions with the teachers, this will create a sense of failure, and again, they lose interest and are not engaged anymore. These effects have been observed by other researchers who attempted to use elements of PB learning in PC settings[3][8].

The second shortcoming is related to the design phase; after the problem, stakeholders, and requirements have been clearly established. Students working in design teams tend to divide the work in chunks that are doable by single students (using the given CAD system) and integrate this separately made work later. Except for the feedback sessions, the work does not need to be integrated, and students tend to work in isolation. This leads to fragmentation lack of focus and understanding of the system as whole - and less cognitive engagement between team members and the teams in the triad. In this phase, the students put most of the effort in mastering the CAD environment and produce the functional and physical designs. Unfortunately, this leads to less communication, low team performance, no collaboration-induced creativity, friction between team members (because they do not understand properly what the others are doing), frustration, and in the end boredom or anxiety. The “flow” mental state sought by using the serious game in the design competition is not achieved any more by some teams. There is no motivation to finish with an exciting result, and there is no intrinsic curiosity left to explore and find alternatives and new ideas for the design. Because the used CAD system is a folder and menu based system that has a graphical interface for IDEF0, the whole work seems to become 99% mouse clicks and menu navigation, at odds with a creative process, and distracting the students from team communication and reciprocal creative thinking. This kind of effects have been observed for many years in real design projects that use CAD systems[7][5], and it is not surprising to find these in PC courses that use CAD systems and teamwork.

An interesting finding came out last year, when members of a triad of students played a digital multi-player serious game, which was developed by the gas industry with RUG collaboration. This triad was the one that developed the bio-gas system, and it had the opportunity to visualize the system they were designing in the form of a business game, which mimicked the development of the bio-gas infrastructure, with implications to the gas markets and investments . At the end of the game, these students were interviewed to find out if the game playing helped them in the process to design their bio-gas system. The most interesting finding of these interviews was that the game actually improved communication within the triad in the “boring” design phase (the game-playing took place in the second half of the course), and helped them to keep an eye

on the whole of the system, and remain engaged in achieving an satisfying result. This was in line with findings in the literature[4]. The identification and validation of these two shortcomings have been done via qualitative research: observation of how students work during tutorial classes, end-of-course survey via open-question forms, and “post-mortem” workshops with students who volunteered to participate, where various aspects of the course were discussed openly, and the findings formalized.

3 Proposed solutions

For the first shortcoming (problem’s lack of realism), the proposed solution is to have a real problem owner, and a real problem. The IEM students who are doing their master thesis in the study year that follows the Systems Engineering Design course are following a three phase curriculum: first a LC course on Research Methodology (with an emphasis on Design Science Research aspects), second a Research Project, and third a Design Project. The last two phases, or at least the last phase, take place in the context of a company, which is the problem owner for the design of the student.

When the Systems Engineering Design course starts (in April), the senior master students who are doing their master thesis project are well advanced in their track, that is, in the middle of the Design Project phase. At that moment, the problem they have to address by their design is very clear, and they started to implement the improvement, or a novel process, or a novel product, or a system that addresses this problem. There are in total 40-50 students whose thesis and design project is in this status. The idea is to recruit a number of students as teaching assistants (TAs) for the Systems Engineering course which is smaller than equal than the number of triads in course. The selection would be based on their previous performance in the course, and the nature of their design (if its scope is a complex, multi-disciplinary system, the better). These students will play the role of problem owners and main stakeholders in the design of a similar system by a triad. There is no need to have an exactly similar scope and nature of the system, but it is expected the problem owner will keep the assumptions made more realistic.

This approach is expected to be advantageous not only for the triad, which will be helped to keep the problem and the design realistic, and drive the design from the problem and not vice-versa. The problem owner student can use the triad as an exploratory design team, and apply their ideas in its own thesis work.

For the second shortcoming (fragmentation of focus during the design phase), the idea is to develop a simple board game that mimics the development of the proposed system. This idea was actually proposed by the students who played the serious game for bio-gas infrastructure. They complained that the digital game was too restrictive and impossible to adapt to their own ideas about the proposed bio-gas system. Because the game had a previous non-digital version, a board-game where game pieces mimicking the components of the system where place on a map, they argued that it would have been more interesting and useful

to have a board game that was easy to change according to the changes they made in their own design. The board can be hand drawn each time the game is played, and new pieces (representing new components) can be improvised easily from old board game pieces, or even 3D printed. The rules of the game should reflect the behavior of the system and its development. The main issue with such a game is its final purpose, which is important for its developers[9]. The current view is that such a game is to be developed to allow stakeholders to play to understand better the system design, and also its potential development. The players who will play the roles initially will be students themselves, but they will design the game having in mind that the real players will be stakeholders. If a problem owner student is attached to a triad that designs a game, this student can participate as a real stakeholder, and also bring the game within the company where the real design project takes place, and engage the potential stakeholders to play the game, communicating the proposed design in a user-friendly manner.

However, the main educational purpose of the game is to prevent fragmentation and bring together the triad members in the phase when they tend to work too much in isolation. To enforce that the game is played regularly, the triad coordinator student should be tasked to organize gaming session twice per week, and have sometimes teacher participation if that is possible. For example, the last feedback session of the course should involve the teachers as players in the newly developed games.

4 Discussion and future work

When applying these ideas, some problems can be envisaged. For example, if there are 8-9 triads in a course, that will necessitate an early planning and strict coordination. The 8-9 appropriate problem owners within the group of senior master students have to be found before the course starts. Also, these problem owners should have design tasks, or at least contexts, that qualify as “complex system designs”. The intention is that for the first year of idea’s application, only a few triads (2, maximum 3) will be matched with a problem owner. At the time of writing, 2 master students who are finishing their master thesis, and a PhD student are already allocated to the role of problem owner. When the course will be taught this year, 3 triads will face a real problem from a company, and their assumptions will be “guarded” by a student tasked for this role.

For the design of the board game, expertise in game design is needed - and it is currently sought after. Initially, there will be only one triad that will attempt a board game design, and only those students who have experience and interest with games will be asked to volunteer for this triad. The intended system design for this experiment will be an electric energy storage infrastructure, modelled on the previous bio-gas infrastructure and its related board game. The teachers and the study program will invest supplementary effort and resources in this triad, and the experience will be carefully documented.

An important follow up to applying these ideas is to assess the impact of these improvements, short term and long term, and communicate the results

and eventually interact with programs that have similar approaches. A related research theme is to investigate if there is an advantage in designing a serious board (+digital) game for the stakeholders in the pre-inception and inception phases of the design of real systems.

5 Conclusions

The use of serious games seems to be promising for improving the effectiveness of PC learning and integrative learning in engineering education, especially in IEM programs. For the moment, there is little experience in applying them, and quick and efficient ways to develop board games that mimic a system's development are yet to be discovered and evaluated.

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