OPEN ACCESS
EURASIA Journal of Mathematics Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
2017 13(7):3565-3585
DOI 10.12973/eurasia.2017.00745a

Setting Engineering Students Up for Success in the 21st Century: Integrating Gamification and Crowdsourcing into a CDIO-based Web Design Course

Donglei Song
College of Computer Science and Technology, Jilin University, CHINA
Adriano Tavares
Centro Algoritmi, University of Minho, PORTUGAL
Sandro Pinto
Centro Algoritmi, University of Minho, PORTUGAL
Hao Xu
College of Computer Science and Technology, Jilin University, CHINA
School of Management, Jilin University, CHINA
Department of Computer Science and Technology, Zhuhai College of Jilin University, CHINA

Received 11 August 2016 ▪ Revised 25 December 2016 ▪ Accepted 11 March 2017

ABSTRACT
Over the past few decades, many researchers have tested course designs that may better engage students in developing countries, accommodate for Millennials' desires to learn and teach at will, and teach students the skills they need for their first jobs. The vision of this paper for a web design course seeks to address these issues for engineering students. The paper first details the 'study everywhere, anytime, from any device and using any tool' approach, following the CDIO (Conceive, Design, Implement and Operate) contextual learning model sustained by gamified crowdsourcing. Then the multi-pronged approach has been tested in a high-enrollment (269-student) web design course at a university in China. The success of integrating the gamification and crowdsourcing techniques into the web design course is then analyzed. Results are positive overall. A linear upward trend is observed in the number of students who completed the course exercises over the duration of the course, marking an increase in student engagement over time.
Keywords: CDIO education, multi-pronged crowdsourcing education, gamification, student-led course design

INTRODUCTION

In the 21st Century, the amount of data available in and created by information technology is exploding. An increase in the use of technology has created more leisure time for many, and teenagers today are often faced with more chances, choices, and freedoms than ever before.

Correspondence: Hao Xu, *College of Computer Science and Technology, Jilin University, Changchun 130012, P.R. China. Tel: +86 13304310608.*
xuhao@jlu.edu.cn

State of the literature

- Teenagers in the 21st Century are often faced with more chances, choices, and freedoms than ever before. People in the age of the Internet have the ability to plan their studies and their futures however they wish.
- However, the teaching methods in China have not yet caught up with these new standards; Chinese classrooms remain traditional, thereby encouraging cramming and discouraging positive student engagement.
- The traditional teaching and learning environment cannot provide students with suitable skills for their future jobs. This creates a mismatch between the skills students develop in the university classroom and those sought after by their future employers.

Contribution of this paper to the literature

- This article promotes a multi-pronged approach for crowdsourcing in engineering teaching with gamification.
- This paper shows that the CDIO framework works to provide an education that stresses the engineering fundamentals for students. Crowdsourcing and gamification are used to make the lifecycle of learning more vital and attractive.
- This new approach can be considered to replace the traditional learning models with contextual learning sustained by gamified crowdsourcing, for the benefit of both students and teachers and provide a more complete and real learning experience for students such that they will be better prepared for their first engineering jobs.

People in the age of the Internet have the ability to plan their studies and their futures however they wish. However, the teaching methods in China have not yet caught up with these new standards; Chinese classrooms remain traditional, thereby encouraging cramming and discouraging positive student engagement (Chen and Bonk, 2008). Old teaching methods that rely on lecturing and rote testing can neither convince teenagers to stay in the classroom, nor provide them with the proper industrial skills (Chen and Bonk, 2008; Han and Zhang, 2008).

Crucially, the traditional teaching and learning environment cannot provide students with suitable skills for their future jobs. This model places a high premium on test scores while overlooking the skills students need to succeed at their first jobs (Li and Li, 2010). This creates a mismatch between the skills students develop in the university classroom and those sought after by their future employers; this skill mismatch has become a serious problem (Global Agenda Council on Employment, 2014). Even students who may graduate at the top of their class may have no idea how to find work or, once employed, how to adapt to their chosen industry (Bartlett, 2013). Although China has high college graduation rates, many graduates struggle to find a job that uses the knowledge they learned in college (Tan, 2006).

Educators of future engineers are therefore faced with a difficult task: how to motivate students to learn while also providing them with the skills they will need on the job. First, a shift in perspective is required. Rather than thinking of how to force students to graduate and to perform well on exams, it is needed to be considered how to attract students to learning and how to teach them practical skills (Kim & Terada-Hagiwara, 2013). If students are given more personalized learning options and better incentives, they may enjoy learning more. As a result, they may be more likely to perform well in their engineering courses. These are the hypotheses tested in the case study, via the implementation of a CDIO-based web design course that utilizes gamified crowdsourcing.

The primary goal of this article is to promote a multi-pronged approach for crowdsourcing in engineering teaching with gamification. The work is done by detailing our approach, describing its benefits, and demonstrating its efficacy in a real-life case study. It is suggested, then, that this approach be applied to other engineering courses as well as to courses in other subjects, so as to increase student engagement while providing students with industrial skills.

BUILDING A CDIO-BASED WEB DESIGN COURSE

The CDIO framework is an education model developed specifically for engineering education. It promotes an authentic learning environment by mimicking the product/system lifecycle of technology companies. This model requires students to Conceive, Design, Implement, and Operate complex, value-added engineering products, processes and systems in teams, as engineers are required to do in the field (Crawley, 2015). The framework is built on the assumption that engineering education is more effective when students learn engineering practices in the context of building functional, necessary products in fast-paced, team-based environments.

For the web design course, it is followed by an adapted waterfall approach as this particular product lifecycle model—i.e., it is preceded by a 'system to be developed' and team selections. Students are invited to present a proposal for their project accordingly to their interest. The adapted waterfall approach has four stages: project establishment, analysis, design, implementation, and test and maintenance. Each stage consists of several interrelated teaching and learning activities (TLAs). Each TLA is comprised of an assignment, the implementation of that assignment, and assessment activities:

- The *project establishment* stage is crucial in motivating students to enroll in and enjoy the web design course. In this stage, each student is invited to form a team with two more peers. However, asking students to form teams in order to learn engineering practices presents its own challenges. Issues that can arise include: (1) since web design is an elective course, enrollees come from different colleges and therefore often do not know each other well; (2) students have different learning abilities and study methodologies and habits; and (3) most students do not know for sure what they can or will do for employment after university. Thus, the first week is devoted to briefly introducing possible career opportunities (e.g., web programmer, interface designer, and product manager). Then, each team is formed more naturally, as students explore new friendships and discuss their preferences for tools, their job interests, and their study habits. Apart from the TLAs just described—introduction to web design toolchains and description of career opportunities—the TLA of 'make a development plan' is also carried out during this stage.

- The *analysis/conceive* stage (the 'C' of CDIO) aims to guide each member of the team to establish the functionalities of the chosen 'system to be developed'—i.e., what the chosen system must do. Basic and relevant essential knowledge will be gradually introduced to equip learners with the theoretical knowledge and reasoning skills needed to solve engineering problems and, as a result, to better conceive the chosen system. The following TLAs are completed at this stage: (1) research requirements, (2) perform use case modeling, (3) perform behavior modeling, (4) complete non-functional requirements analysis, and (5) write and present requirement specifications.
- The *design* stage ('D') consists of two main tasks: design a general architecture and a detailed architecture for the given system. Accordingly, its main purpose is to guide the teams in specifying how to build the chosen system. More advanced knowledge will be introduced here to equip learners with the technical skills required to implement the detailed architecture. The following TLAs occur at this stage: (1) determine a general system architecture, which includes module and database structures, (2) design the SQL database, (3) design the layout for the system interface, (4) design the system navigation, and (5) write and present the system design specification.
- The *implementation* stage ('I') requires students to implement the chosen system according to the established functionalities and methods, while leveraging the convergence between knowing and doing. In this stage, the following TLAs are carried out: (1) design the code for all system modules or select the code from the crowdsourcing repository, (2) integrate all system modules, and (3) optimize system performance.
- The *test and maintenance* stage (or 'O'/'Operate' stage) requires students to test the implemented system and fix any errors found during the testing process. The following TLAs are associated with this stage: (1) system functional tests, (2) system integration tests, (3) system safety tests, (4) system performance tests, (5) bug identification and bug fixes, (6) system deployment, (7) development of a system maintenance plan, and (8) test and maintenance report generation and presentation.

Since CDIO promotes goal-oriented, project-based learning, in the very first class the aims and intended learning outcomes (ILOs) are clearly stated. In fact, they are distributed to the students prior to them starting any project or receiving any classroom instruction. **Table 1** presents the ILOs developed for the web design course, split into technical skills vs.

Table 1. Web Design Course ILOs

		Descriptions
Technical Skills	A	Mastering core principles and knowledge to design and develop web-based systems
	B	Understanding and utilization of modularity, Cascading Style Sheets, and relationship between organization of information and graphic design
	C	Demonstrating programming and problem solving skills as applied to web-based development
	D	Developing and presenting design specifications and concept alternatives
	E	Demonstrating technical skills required of Web Designers through the use of W3C standards, HTML5, computer graphics, Client Scripting, User-Centered Design, and Content Management Systems, server-side programming (e.g., using PHP), and SQL languages
	F	Possessing technical ability to grasp web-based systems through whole design process using WYSIWYG web development software
Strategic Skills	G	Know the societal (i.e., ethics, morality, professionalism, and social responsibility), environmental, business, economic, and political relevance of what is being taught
	H	Possess a willingness to learn continuously and to proactively update and extend knowledge to solve real-life problems
	I	Be inquisitive, innovative, able to conceptualize issues, and adaptable to changes
	J	Cope well with pressure, be resilient, manage stress, meet deadlines, prioritize work, be committed, self-motivate, be effective in working with others, acquire good presentation and writing skills, and address globalization issues

strategic/soft skills. These ILOs were also mapped to CDIO learning outcomes using Crawley et al. (2011)'s CDIO Syllabus 2.0 and aligned to TLAs and assessment tasks (ATs).

It is believed that the appropriate tradeoffs between breadth and depth in web design are different for different career paths—e.g. for a future software engineer vs. a future product manager. Consequently, each TLA was assigned a percentage to represent how much of the overall learning and teaching effort should be comprised by that TLA for a given career opportunity or team interest level.

A MULTI-PRONED APPROACH FOR CROWDSOURCING EDUCATION IN A WEB DESIGN COURSE

Nowadays, several new technology movements (e.g., mobile-first, quantified self, Bring Your Own Device, the Internet of Things) are gaining momentum. The crowdsourcing movement, a collaborative problem-solving approach that outsources tasks to a community of qualified contributors through an open call (Howe, 2012), is one of them. Broadly speaking, the crowdsourcing conceptual model consist of several elements, such as: the problem, the community, collected artifacts or outcomes, process type and activities, the rewarding schema, the call for participation, and the medium (Howe, 2012; Fritz et al. 2009). In particular, a multi-pronged educational crowdsourcing model has been proposed. This model has the following benefits: (1) a quality-assured course design driven by qualified instructors and researchers and their teaching artifacts; (2) a crowdsourced teaching experience involving several instructors within the space of each classroom. A peer-review along with instructors' real-time

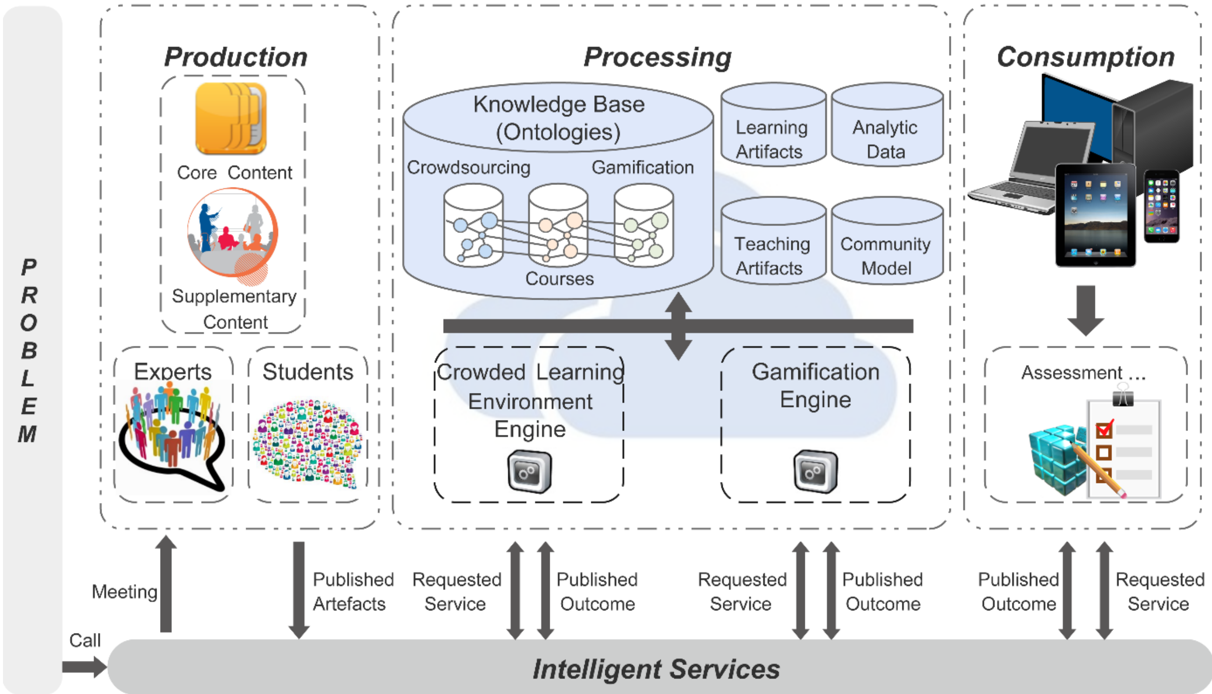

Figure 1. Conceptual Model of the proposed Gamified, Crowdsourced CDIO Learning Environment

feedback on student progress, goals, ambitions, and contributions are used to supplement automatic electronic assessments. In sum, crowdsourcing various elements of a CDIO web design course should improve the quality of the course design and materials, decrease the effort required by each individual instructor in the classroom, and provide students with better, more informative feedback.

Figure 1 shows Crowdsourcing model. This model is mapped to the web design course as follows:

- The *problem* is the co-creation of a student-led CDIO-based web design course through the design, alignment, and implementation of ILOs, TLAs, and ATs.
- The *community* is assembled from the content expert crowd (i.e., instructors and researchers) at 3 universities from China, Portugal and Japan. Students are also recruited as part of the crowd to ensure high quality content production while also including a diversity of views in the resulting course artifacts.
- *A collaborative problem-solving process and collaborative activities* are achieved through several intelligent services (e.g., semantic retrieval, interlinking and matching of syllabuses); educational activities such as core content creation for a web design course curriculum; and designing TLAs, ATs, and ILOs while aligning and deploying them all into a product/system lifecycle model. This collaboration

creates a pleasurable learning environment for students while also setting them up for a lifetime of curiosity based on strong community interaction.

- The *rewarding and reputation schema* is gamified to attract more participation from the student crowd. The instructor crowd is implicitly rewarded by enhanced productivity, which, in turn, allows them to provide more personalized attention to students. Both students and teachers are seen to benefit.
- The success of the *call for participation* of the content expert crowd relies on the pre-existing cooperation between the three partner universities. Students were motivated to participate by providing them with incentives: participate in a fun, new kind of web design course; get involved with your fellow students; be a part of popular technology movements; and so on.
- The *medium* consists of web and multimedia technologies. It must contain the right percentage of interactive, in-class lessons while leveraging the BYOD movement to meet different learning styles. Allowing students to commit their time and own devices (e.g., tablets, smartphones and laptops) to learning at their own pace also plays into the strengths of the Millenial generation.

The Crowdsourced, CDIO-based Course Model

To design a CDIO-based learning and teaching environment that leverages the '*study everywhere, anytime, from any device and using any tool*' motto, a three-layered gamified crowdsourcing course ontology is proposed (see **Figure 2**, **Figure 3**, and **Figure 4**). This ontology integrates learning/teaching entities such as a syllabus, ILOs, TLAs, ATs, learning materials, learning subjects, assignment, a teaching schedule, instructors, and students, as well as the aforementioned crowdsourcing conceptual model. It promotes course evolution in order to better fit career opportunities at each partner university and students' learning needs.

The proposed ontology aims to enhance automation and interoperability in a gamified, crowdsourced learning environment. Other benefits include:

- *Fostering BYOD and the maker movement* by allowing students to use their own personal devices. This freedom increases student participation and allows students to tailor the course experience to their learning styles. It also 'makes' CDIO experiences in a collaborative way, via the sharing of experiences and mentoring, all in a natural setting of discovery. For example, entities such as *'Medium'*, *'Task'*, *'Community'*, *'Artefact'* and *'TLA'* in **Figure 2** leverage the two movements in the proposed CDIO learning environment.
- *Offering a flipped classroom model of learning* by scheduling the time spent both in and out of the classroom. This serves to shift ownership of the learning process to students; they decide when learning starts and when it ends. Entities such as *'TLA'*, *'Schedule'*, *'Location'*, and *'Availability'* in **Figure 3** support the configuration of the flipped classroom.

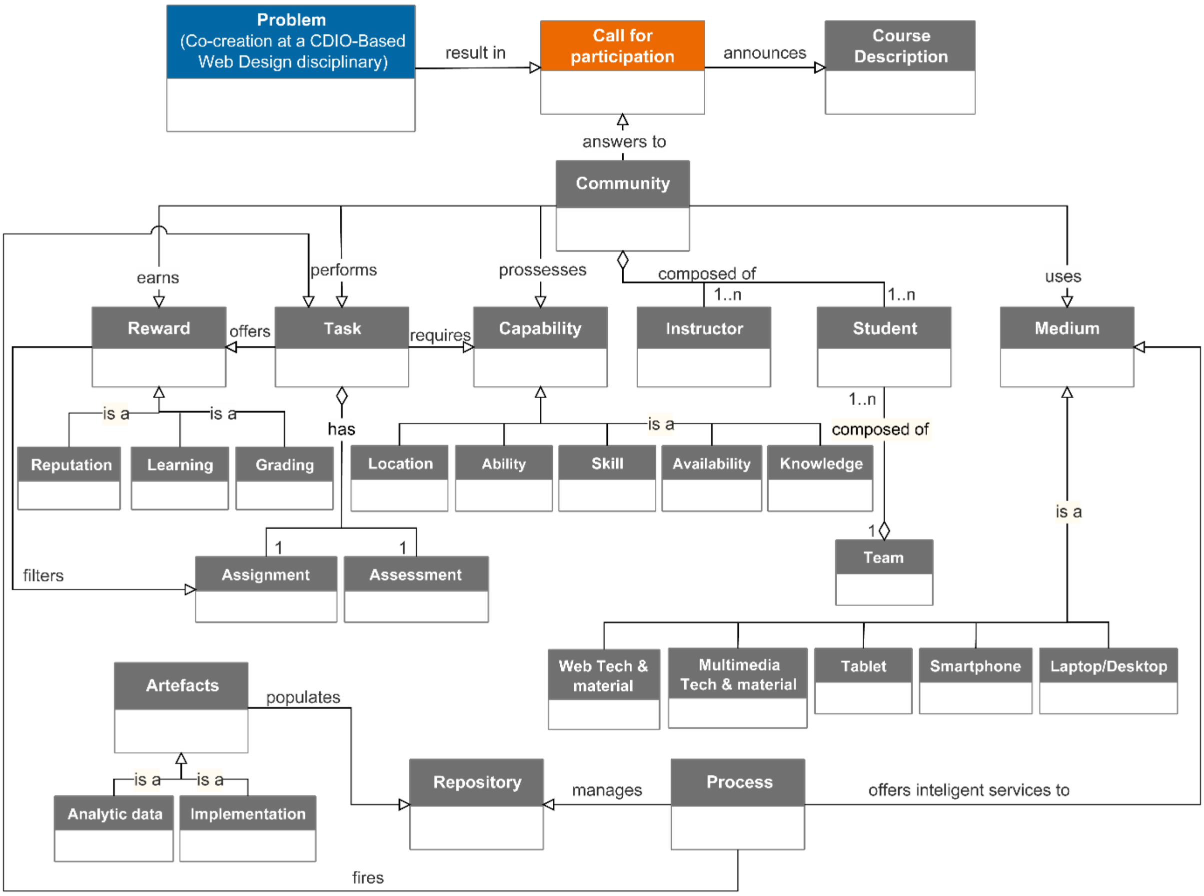

Figure 2. Classes and Relations of the Crowdsourcing Ontology

- *Motivating and engaging students* by making them co-creators of the classroom and the course in which they are enrolled (i.e., fostering a student-led course design). This is in lieu of being simple consumers of teacher lectures. Furthermore, analytic data on student behavior will be collected in this case study and analyzed retrospectively in order to optimize long-term engagement. Entities like *'Team'*, *'Learning Path'*, *'ILO'*, *'TLA'*, *'AT'*, *'Curiosity Pool'* and their relations (see Figure 3) encourage co-creation, creativity, and curiosity.
- *Promoting creativity and curiosity* by predicting some possible issues that will arise during the CDIO experiences and providing a pool of curiosity questions and small practical examples tackling similar issues (see *'Curiosity Pool'* entity in Figure 3). Those questions and hands-on examples are linked to each TLA, and bonuses are assigned in the web design course for those students that discover them alone.
- *Automatic generation of assessments* is achieved by linking question pools with core content entities into the repository model and targeting the assessment of specific

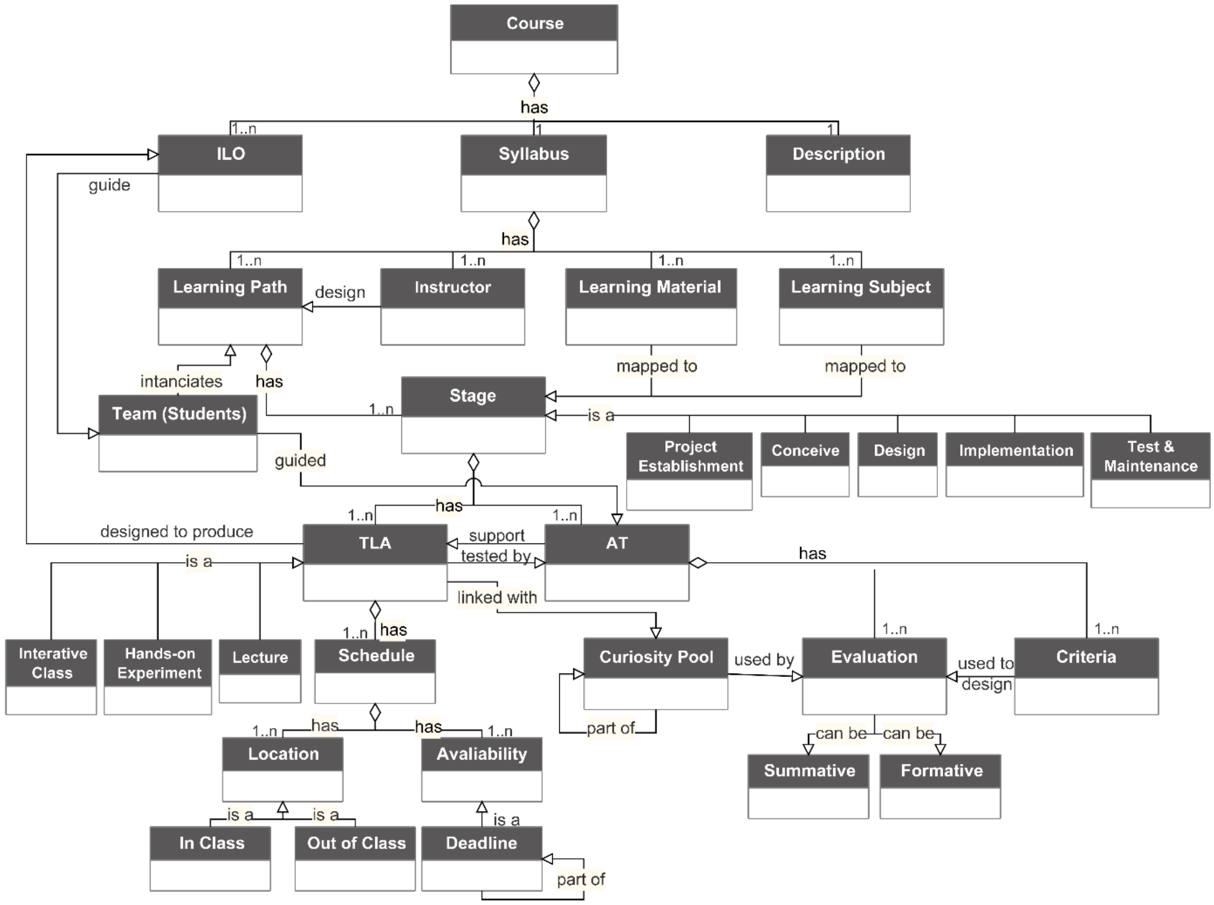

Figure 3. Class and Relations of the Crowdsourcing Ontology

course content. The entity *'Curiosity Pool'* in **Figure 2** comes with questions and associated answers for the automatic evaluation of assessment tasks.

Figure 4 presents the proposed three-layered, CDIO-based, gamified, crowdsourced learning environment. It consists of crowdsourcing, course and gamification ontologies, and some partial relationships among them. Examples of these relationships include: (1) the 'Reward' entity at the crowdsourcing layer maps to the 'AT' entity at the course layer, which maps to entities like 'Point' and 'Badge' at the gamification layer; (2) the 'Call for participation' entity at the crowdsourcing layer maps to the 'Description' entity at the course layer; (3) the 'Process' entity at the crowdsourcing layer maps to 'TLA' and 'Syllabus' at the course layer, which maps to entities like 'Point' and 'Badge' at the gamification layer (4) the Student/Instructor entity at the course layer maps to 'Player' entity at the gamification layer (i.e., a student is a player); and (5) 'ILO' at the course layer maps to 'Goal' at the gamification layer.

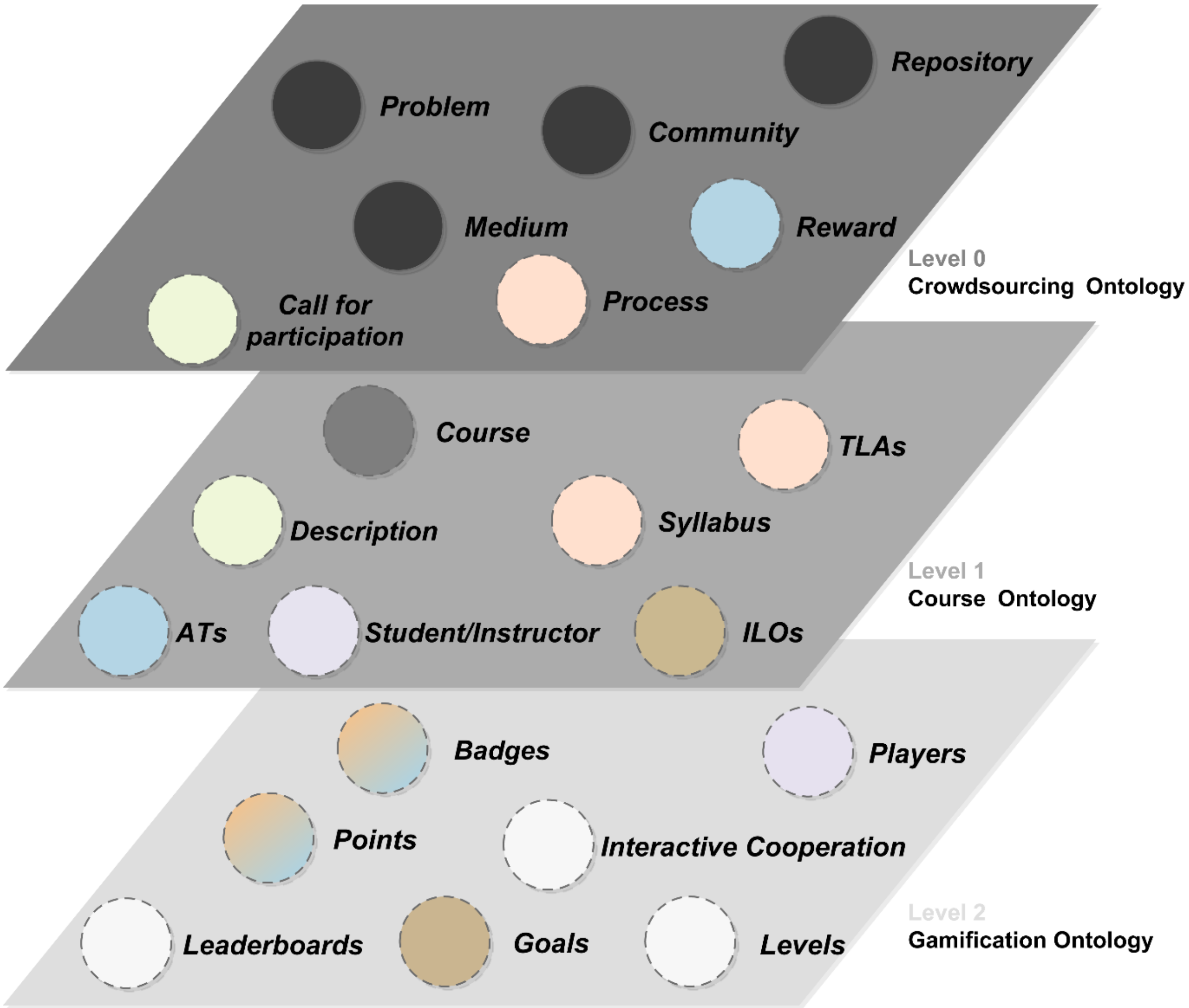

Figure 4. Three-Layered Ontology of the CDIO-Based, Gamified, Crowdsourced Learning Environment

Crowdsourced, CDIO-Based Teaching and Maintenance Models

Figure 5 describes the management of the proposed CDIO-based teaching model, starting with team creation and the co-designed learning path. Team members, assisted by instructors, decide among themselves what the intended project will be. Then, they will implement their favorite and appropriate learning path, bound to core content for each instructional stage. To leverage the maker movement and its exciting, DIY (Do-It-Yourself) motto, a few TLAs are assigned to individual team members during the learning path. Students are also advised to browse the repository outside class for similar and alternative content; this strategy promotes autonomy in student learning. The remaining TLAs—that is, the majority of them—are completed collectively to promote a DIT (Do-It-Together) attitude, the other motto of the maker movement.

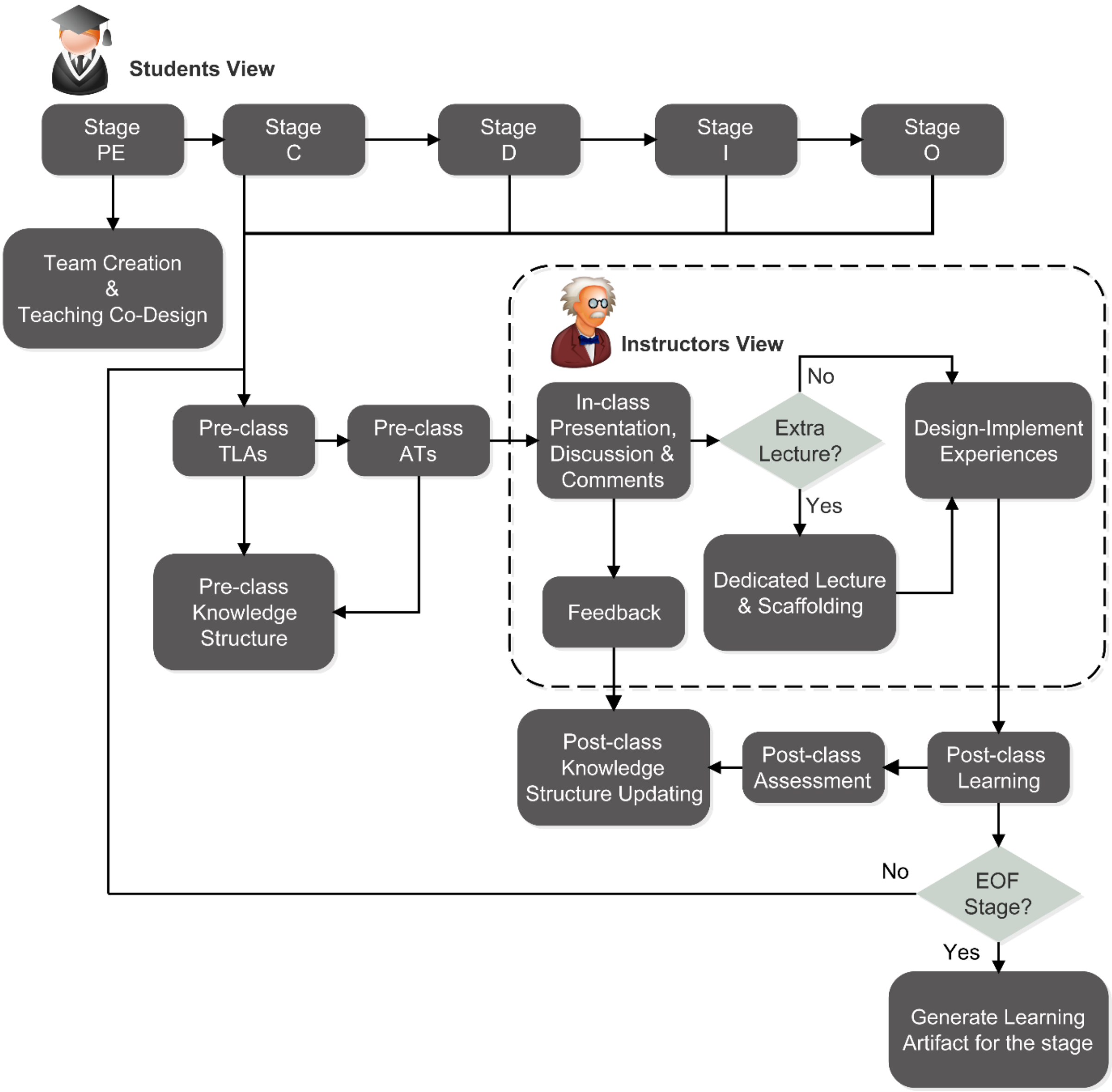

Figure 5. Proposed Teaching Model for the Flipped, CDIO-based Environment

Across the learning path, instructors' feedback is collected automatically by the system (e.g., for system feedback). At the end of each stage, the learning artifact is used to populate the repository via the community model and the learning artifacts, respectively (see **Figure 1**). After each session, a self-report of interest and engagement, enjoyment, confidence, disappointment, sadness, frustration, and feelings of mastery are submitted by students using an Excel style sheet with associated percentages.

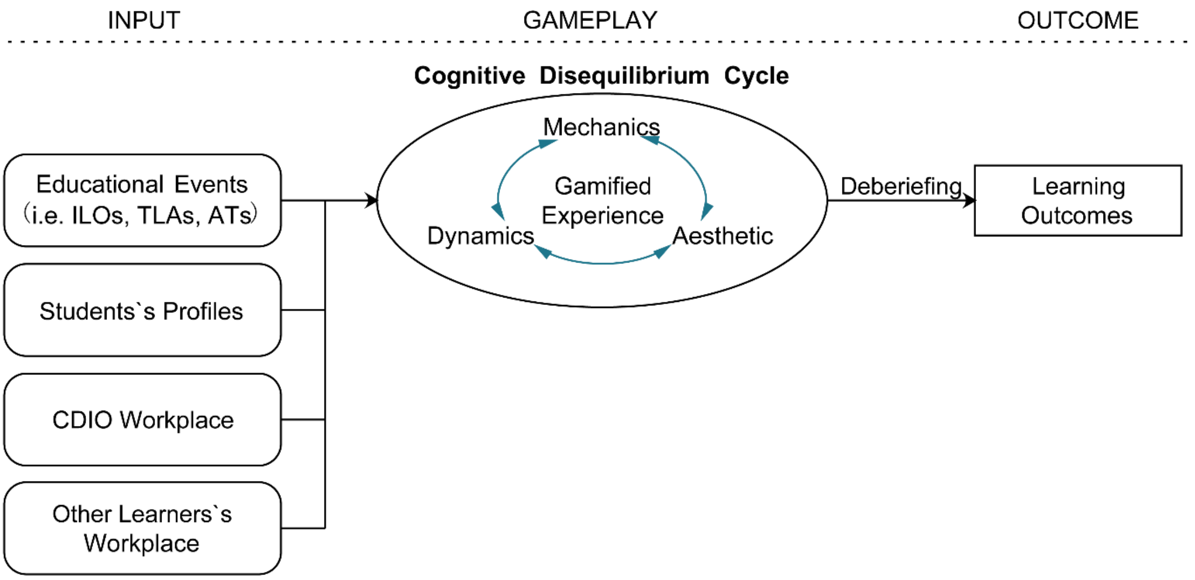

Figure 6. Co-Designed Model Combining MDA framework and the Input-Process-Outcome Game Model

A GAMIFIED, CROWDSOURCED, CDIO-BASED LEARNING MODEL

Gamification is a proven, powerful strategy for engaging, influencing, and motivating groups of people. It applies game mechanics into non-game activities and processes, thereby making learning more fun (Deterding, 2011; Deterding et al. 2013). The proposed CDIO-based learning and teaching environment, a co-designed model combines the Mechanics-Dynamics-Aesthetics (MDA) framework (Hunicke et al. 2004) with the Input-Process-Outcome Game Model (Garris et al. 2002). To do this, gamified application dynamics or characteristics to the course content, student profiles, and makerspaces are aligned. These principles include: empowered learners, problem-solving and understanding, and learning concepts. The MDA model formalizes the creation of gamification experiences based on its three principles of mechanics, dynamics, and aesthetics (Hunicke et al. 2004). **Figure 6** shows the interdependent relationship among the elements of the framework. The ontology presented in **Figure 7** provides an abstract, quick-and-easy understanding of co-designed gamification. The ontology in **Figure 8** provides more details for a deeper understanding of the conceptual model.

Co-Designed Gamification Model

Mechanics can be defined as the processes that drive actions forward (Hunicke et al. 2004) by dictating the outcome of interactions within the game environment. These mechanics include an input, a context, a process/gameplay, and an output (**Figure 6**). The key component of the co-designed model is the cognitive disequilibrium and resolution cycle (a.k.a. engagement loops) through assimilation and accommodation. This fosters a motivating gamified experience for users, and encourages the exploration of self-invented ideas.

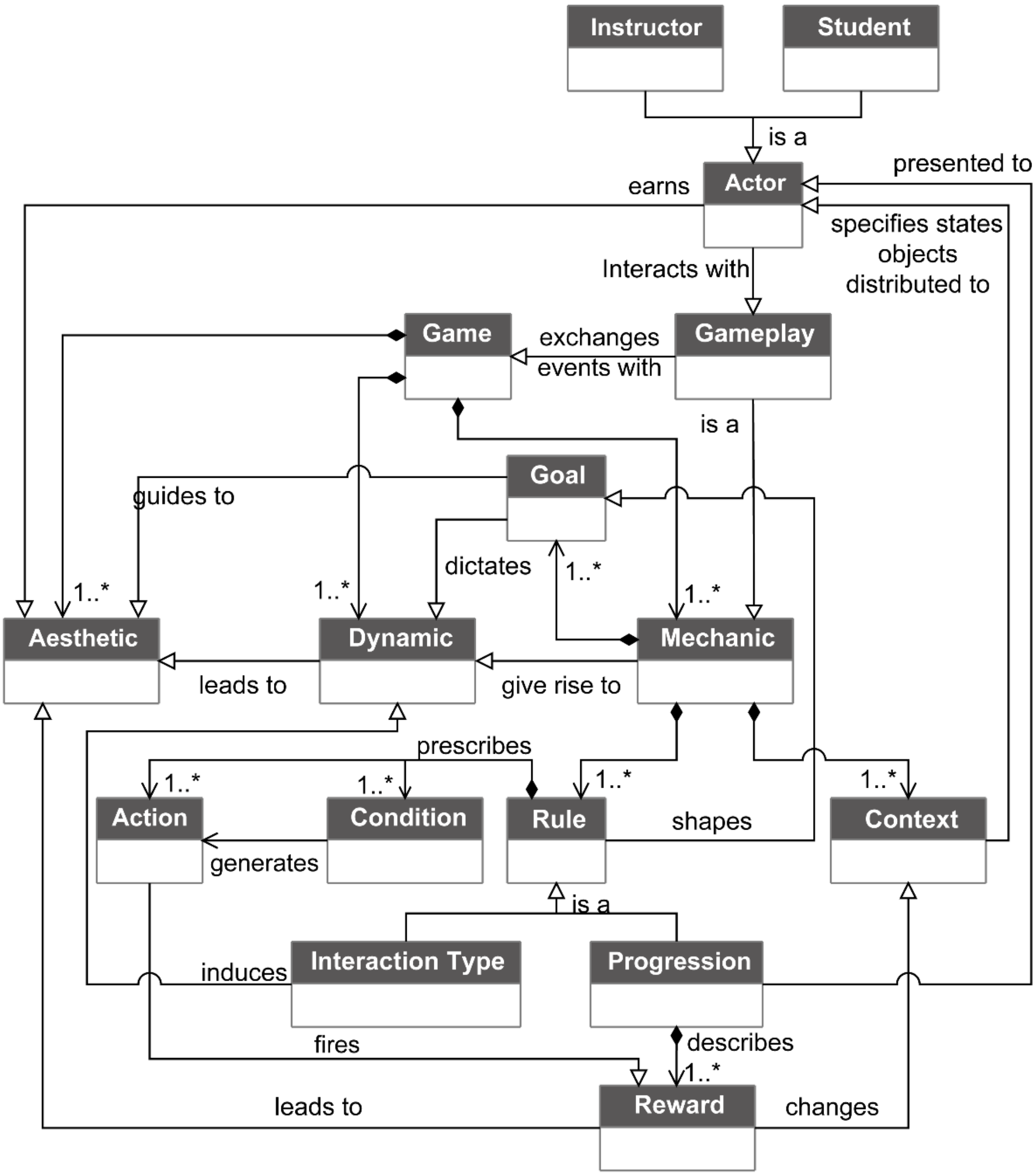

Figure 7. Classes and Relations of the Gamification Ontology

Importantly, the experience does not exceed the capacity of the player to succeed (Eseryel and Ifenthaler, 2012). The interdependent relationship of the gamification principles of mechanics, dynamics, and aesthetics is described in **Figure 7** by the entities *'Mechanic'*, *'Dynamic'* and *'Aesthetic'*, which are ontologically linked by the object properties *'gives rise to'* and *'leads to'*.

The Alignment of Educational Events with Gamified Principles

Approaching gamification of learning from the designer perspective leads first to the fundamental question of, *'How can we best apply gamification to a chosen learning and instructional environment?'* The above question was answered by splitting it into smaller questions. Hsin-

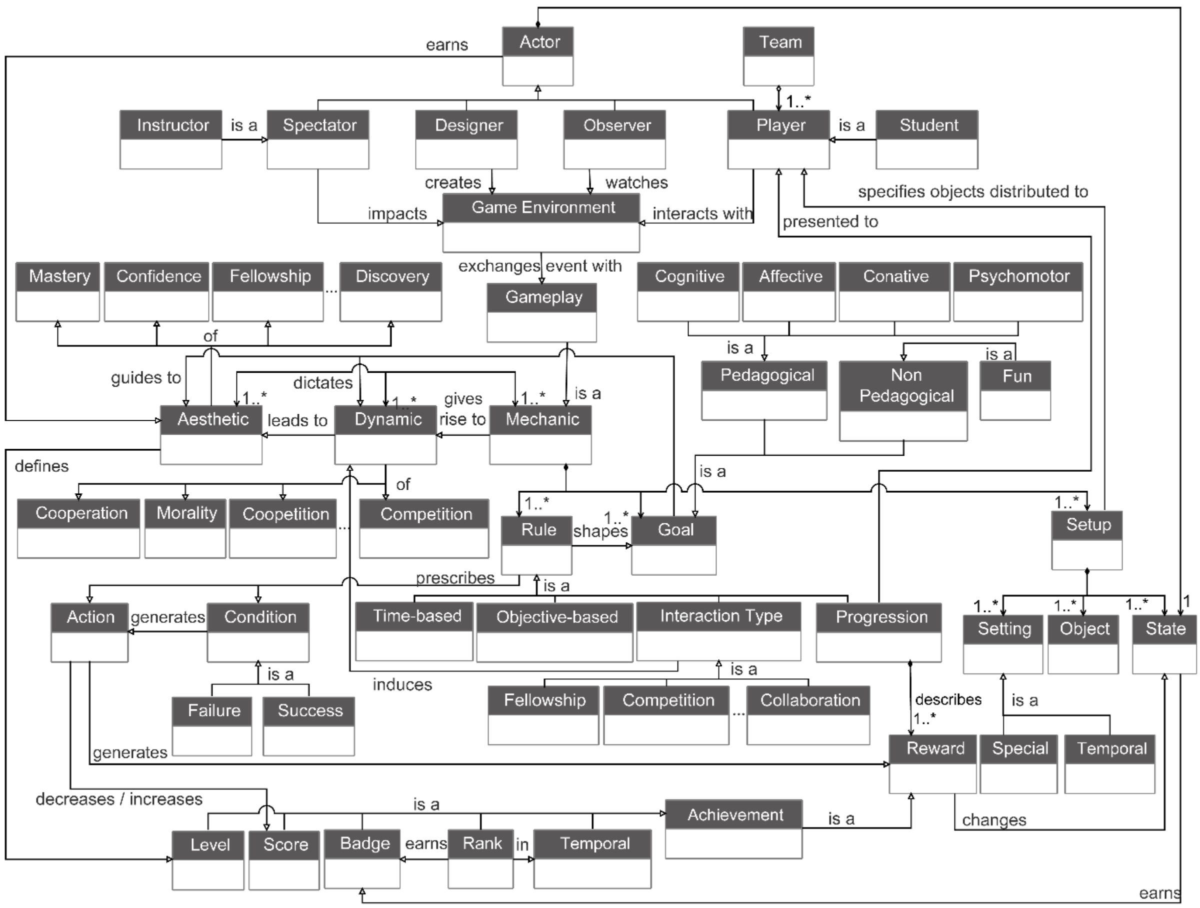

Figure 8. More Detailed Classes and Relations of the Gamification Ontology

Yuan and Soman (2013) propose five sequential steps for incorporating game elements in education. It was elaborated how these smaller questions are addressed by the conceptual model here:

- *How can we empower learners and thereby maximize their responsibility?* The answer is to implement a student-led course design. This design is created by leveraging the BYOD movement, student customization of the learning path, the creation of peer teams, diverse learning artifacts that suit diverse learning styles, peer-review of produced learning artifacts, project choice, and self-paced learning.
- *How can we apply gamified learning scenarios out of the classroom while minimizing the interruption of the flow by balancing gameplay with in-class instructional activities?* Not all prescribed TLAs and ATs are easily gamified; the in-lab, hands-on CDIO experiment is one such activity. Thus, the TLAs and ATs are tightly-coupled with the gamified application. The constant cycle of cognitive disequilibrium and resolution is devised to promote the desire for mastery by embedding practical videos or slideshows that explain how to use tools. It was relied here on the

definition of gamification given in Hutch & Carpenter (2014): 'The incorporation of stimuli into an activity to influence people's actions toward desired outcomes.'

- *How can we balance different types of incentives that appeal to different learners' profiles, instead of emphasizing one over others?* This model aims to leverage different rewards for differing learning styles, interests, and intrinsic motivations. All gamified tasks are designed and implemented to be sufficiently engaging, though they rely on only one external reward: the certificate. In **Figure 8**, the *'Reward'* entity is semantically and indirectly linked to the *'Mechanic'* entity through the following chain of entities and object properties: a set of *'Reward's 'is described by' a 'Progression'*, which *'is a' 'Rule'*, and a set of *'Rule's 'are aggregated by' a 'Mechanic'*.
- *How can we match ILOs, ATs, and TLAs to gamified scenarios that are most suitable for the instructional goals?* The main challenge is starting with the educational event and learning content to anticipate compelling dynamics that can emerge from possible gamified scenarios. Then, people can appropriately support those scenarios with developed mechanics to match each ILO, as proposed in **Table 1**, to the identified mechanics, dynamics, and aesthetics. Taking aesthetics experiences as the goals of gameplay (i.e., the learning outcomes), in **Figure 8**, the interdependent relationship of the gamification principles is semantically enforced by entities and an object property that map aesthetic experiences to the set of goals as prescribed by the gamified mechanics—i.e., as et of *'Goal'*s, *'guides to' 'Aesthetics'*. Although not visible in **Figure 4**, *'TLA'* and *'AT'* entities at the course layer map to the *'Rule: Action'* entity at gamification layer (see **Figure 8**) while AT's assessment criteria or TLA's time-based constraints can be mapped to *'Rule: Condition'*. Additionally, the set of *'Mechanic: Setup: Object'* at the gamification layer (**Figure 8**) consists not only of virtual gamified elements like player-tokens, but also learning materials at the course layer.

In **Table 1**, the desired aesthetic experience of mastery was prescribed at the inputs 'C' to 'F', of communication at inputs 'D' and 'J', of understanding at inputs 'A' and 'B', of morality at input 'G', of discovery/curiosity/creativity/challenge at inputs 'H' and 'I', of collaboration at input 'J' and of resilience at input 'J'. **Figure 8** presents several types of dynamics/aesthetics ontologically linked by the object property 'of' that can be also represented by the inverse object property 'is a'. **Table 2** can be filled from left to right with the anticipated compelling dynamics and supporting mechanics.

TESTING THE CONCEPT IN A WEB DESIGN COURSE IN UNIVERSITY

The gamified, crowdsourced, CDIO-based model was put to the test in a large-scale web design class (N=269) in a university in China. The experiment lasted for about seven weeks. In previous years, this class followed the traditional teaching and learning model; teachers gave lessons following a syllabus without skill focuses, all students completed the same exercises, and took the same final exam.

Table 2. Predicted Dynamic and Supporting Mechanics for the Alignment of Educational Events with Gamification Principles

Predicted Dynamics of	Developed Mechanics**	Gamified*
Mastery	Tutors embed practical video or PowerPoint slideshow before class to explain how to use tools as well as solve issues similar to those that will happen in the next in-lab experiments. The user behavior of each student will be recorded as points. After finishing watching a video or PowerPoint slideshow, the player-token will receive a star as a reward. The stars are exchanged for valuable learning material or special awards (e.g., visiting factories or offering internships) in future versions.	Only partially
Demonstration	Tutors do demonstrations before students` free creation. To help the students be familiar with the 'process', tutors lead them to finish the demonstrations with the help of multimedia artifacts.	No
Autonomy	Students have freedom to choose the learning materials and exercises during the learning progress. In the final exam, students get a final task of differing difficulty. This is just like a boss stage in a real game.	Yes
Collaboration and cooperation	In the course, students receive basic skills training and then arrive at the following exercises a final exam on a team-by-team basis. Students use preskills to work on their programs. Peer review along with teacher review encourages better cooperation between students and fosters a collaborative final project.	Only partially
Feedback	Feedback is necessary at each learning step. For example, when the student is doing exercises alone and gives a correct answer, the player-token should show a mark. The learning results are also available at any time if they want to know their learning process.	Only partially
Progression	We use a stage-mode to provide the students with a game-like learning environment. This stage-mode is fit for learning progress, which shows obvious stages, such as CDIO. Additionally, the stage-mode brings students discovery, progression, and infinite gameplay. Students do exercises every week after school to accumulate their points. At the same time, they acquire skills according to their interests and target career. Each student makes his player-token progress on his or her own.	Yes
Curiosity	During the whole learning process, the following part of the learning map will be covered with mists. The gamified system will invite students to use the pool of curiosity questions and small practical examples and points will be assigned accordingly. Only finishing the exercises can make the player-token move and dispel the mists.	Yes
...		

* Tasks not or partially gamified are tightly-coupled designed to the gamified application to minimize the interruption of flow or engagement loops.
** All mechanics will be italicized.

According to the incentive model and TLAs, the seven weeks are divided into four stages, which all map to CDIO concepts. The first week aims to have students Conceive, the second week aims to have students Design, the third week aims to have students Implement, and the forth to seventh weeks aim to have students Operate. Students team up at the fifth week and then work together on their project. A learning platform was designed for this, as is

Figure 9. User Interface of the Platform

shown in **Figure 9**. Each column of tasks represents one week. The ILOs are classified by career suggestion (i.e., programmer, designer or product manager). Each week, there were many different exercises available for students to complete, with differing knowledge/skill weights and degrees of difficulty. Some of them focused on using tools, whereas others focused on design or management.

The stage-mode is fit for learning progress, which is broken into discrete stages such as CDIO. In the first three stages, there are several exercises with ILOs, like every task in each stage of game. Students are regarded as understanding the teaching content if they choose one of the exercises and finish it. Before the final exam is presented in stage 4, students team up with others. A learning report is given to each student with learning activities, exercise completion rates, a career suggestion and teammates' recommendations for each student, as is shown in **Figure 10**. The report serves an important role in providing students with timely feedback. The final exam is designed as a boss monster when students come into the operate stage. The final exam is divided into five levels. Each level has aims with different difficulties following ILOs. Goal-management is simple and implemented by choosing the suitable level according to team capability.

The final exam marked the end of the course. It was followed by an anonymous questionnaire. The score of the final exam was calculated according to the level students choose and their classmates. The questionnaire was given to the students who chose to use the platform, which surveyed the learning effects of self-assessment, surveyed the students' feelings about the platform, and collected comments and suggestions. There was also a small

Figure 10. Personalized Feedback

interview with the one student who chose this course for two semesters in a row because he could directly compare the previous course model to the course that the same teacher implemented.

Results

The engagement level of the students who used the platform was analyzed by tracking how many students of the total number of students accepted the weekly, career-specific exercises and, of that subset, how many of those students went on to complete the exercises. During the whole process of the class, 226 students attend the platform to do exercise. Additionally, how well they learned the target material was also analyzed by calculating the average final exam score and the percentage of students who achieved "excellent" scores on the final (80 or higher).

As illustrated in **Figure 11** and **Table 3**, students accept and complete more exercises in the 2nd and 3rd weeks, but then accept and complete fewer of them in Week 4. Nonetheless,

Table 3. Completion of Exercises by Week

	Acceptance	Completion	Percentage of Students Who Completed the Tasks They Accepted
1st week	175	149	85.14%
2nd week	172	151	87.79%
3rd week	150	143	95.33%
4th week	147	125	85.03%

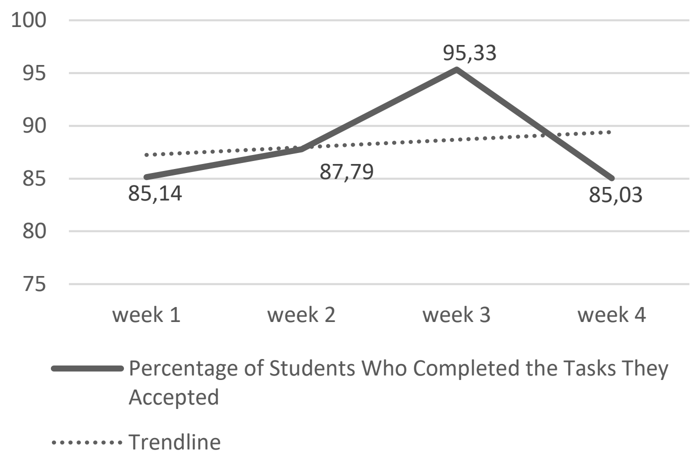

Figure 11. Tendency of Completion

Table 4. Excellent Exam Performance (i.e. over 80%) on the Final Exam

	Average score	Standard deviation	Score over 80		
			Frequency	%	Accept Gamification
2nd semester	82.08	6.16	242	90	221
1st semester	80.56	7.14	192	71	No gamification

the average completion rate rises linearly. Of the total number of participants, 96 students completed all four weeks of exercises.

The number of students who scored over 80 of the final exam is shown in **Table 4**. The average score for the entire class is over 80, which is considered excellent by Chinese standards. Crucially, there is a notable increase of 19% on the number of people who scored over 80 from last semester.

In the questionnaires probing student opinions on the course, 72% of students were satisfied with the platform. Almost all of the others expressed neutral opinions. Nine students pointed out that some improvement was still required in the user interface and gamification design. Only one student expressed his dislike of the platform. The student who chose the course twice reported that *"I prefer this kind of course than the prior, traditional course. I enjoyed this kind of personalized learning very much. I like this participation style, it feels like a game."*

DISCUSSIONS AND CONCLUSIONS

The results demonstrate that a CDIO, crowdsourced, gamified teaching and learning model can effectively engage students and provide better knowledge conversion for engineers. The results of the case study at the university are very positive overall. The completion rate of doing exercises every week rises linearly on average. Nevertheless, the results are not entirely positive. The number of exercise acceptances and completions decline in Week 4. The possible reasons could be that students started anticipating the exam and stopped focusing as much on the individual exercises. Or maybe the students got fatigued. This model will model may need to be improved upon in the future. However, the satisfaction of the students is generally high, according to the questionnaire.

Targeted, effective learning should be the goal of university courses. This paper shows that the CDIO framework works to provide an education that stresses the engineering fundamentals for students. Crowdsourcing and gamification are used to make the lifecycle of learning more vital and attractive. As a result, it is believed that it is worth considering combining the CDIO framework, crowdsourcing, and gamification into future courses. Overall, it is aimed to replace traditional learning models with contextual learning sustained by gamified crowdsourcing, for the benefit of both students and teachers. At the same time, this model provides a more complete and real learning experience for students such that they will be better prepared for their first engineering jobs.

People need more practice, fun, interaction, and technology in the classroom so that the educators can offer more incentives to students. To this end, in the future, it is also aimed to improve education via interdisciplinary research and human-computer interaction.

ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China (No. 61300147, 61472159), the Science and Technology Program of Changchun (No. 14GH014), Development Project of Jilin Province of China (No. 20160204022GX, 20170101006JC, 20170203002GX), China Postdoctoral Science Foundation (No. 2016M601379) and MOE Research Center for Online Education Quantong Education Foundation (No. 2017YB131). This work is also supported in part by Premier-Discipline Enhancement Scheme supported by Zhuhai Government and Premier Key-Discipline Enhancement Scheme supported Guangdong Government Funds.

REFERENCES

Bartlett, W. (2013). Skill mismatch, education systems, and labour markets in EU Neighbourhood Policy countries. *WP5/20, Search Working Papers*.

Chen, W., & Bonk, C. (2008). The use of weblogs in learning and assessment in Chinese higher education: possibilities and potential problems. *International Journal on ELearning*, *7*(1), 41.

Crawley, E. (2015). The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education, 2001.

Crawley, E. F., Malmqvist, J., Lucas, W. A., & Brodeur, D. R. (2011). The CDIO syllabus v2. 0. An updated statement of goals for engineering education. *In Proceedings of 7th International CDIO Conference, Copenhagen, Denmark*.

Deterding, S., Björk, S. L., Nacke, L. E., Dixon, D., & Lawley, E. (2013). Designing gamification: creating gameful and playful experiences. *InCHI'13 Extended Abstracts on Human Factors in Computing Systems* (pp. 3263-3266). ACM.

Deterding, S. (2011). Meaningful play: Getting gamification right. *Google Tech Talk*.

Eseryel, D., & Ifenthaler, D. (2012). Assessment in Game-based Learning: Foundations, Innovations and Perspectives. *Springer*.

Fritz, S., McCallum, I., Schill, C., Perger, C., Grillmayer, R., Achard, F., ... & Obersteiner, M. (2009). Geo-Wiki. Org: The use of crowdsourcing to improve global land cover. *Remote Sensing*, 1(3), 345-354.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & gaming*, 33(4), 441-467.

Global Agenda Council on Employment. (2014). Matching Skills and Labour Market Needs Building Social Partnerships for Better Skills and Better Jobs. *World Economic Forum, Geneva, Switzerland.*

Han, Z., & Zhang, Z. (2008). Integration of Game Elements with Role Play in Collaborative Learning—A Case Study of Quasi-GBL in Chinese Higher Education. *In International Conference on Technologies for E-Learning and Digital Entertainment* (pp. 427-435). Springer Berlin Heidelberg.

Howe, J. (2012). The Rise of Crowdsourcing. *Wired*, 14 (6), June 2006.

Hsin-Yuan Huang, W., & Soman, D. (2013). A practitioner's guide to gamification of education. *Toronto, ON, Canada: Rotman School of Management*.

Hunicke, R., Leblanc, M., & Zubek, R. (2004). MDA: A Formal Approach to Game Design and Game Research. *Challenges in Games Ai Workshop* (pp.1--5).

Hutch, C (2014). The gamification framework for business innovation. http://blog.hypeinnovation.com/the-gamification-framework-for-business-innovation

Kim, Y. J., & Terada-Hagiwara, A. (2013). A survey on the relationship between education and growth with implications for developing Asia. *Journal of International Commerce, Economics and Policy*, 4(01), 1350005.

Li, W., & Li, Y. (2010). An analysis on social and cultural background of the resistance for China's education reform and academic pressure. *International Education Studies*, 3(3), 211.

Tan, S. G. (2006). Employment pressures on college students and changes of their employment value. *Journal of Beijing Institute of Machinery*, 1, 025.

http://iserjournals.com/journals/eurasia