

Toward a Process-Centered Approach for Systems Engineering Education

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Toward a Process-Centered Approach for Systems Engineering Education

Keywords Systems Engineering Education, Systems Engineering Standards, Competency Models, System Life Cycle Model, Project Based Learning.

Introduction

Time has gone when industrial companies recruited their employees only based on a fine technical background. Nowadays, these companies deal with complex and multidisciplinary systems, and their mastering requires much more than mere technical excellence. Today's engineers need to be good team workers, adept communicators, and lifelong learners [1]. In addition to producing the expected client outcomes, a major engineering project has to satisfy various stakeholders while ensuring an optimization of time, cost, energy and other resources throughout its entire life cycle. In view of these challenges, a growing number of companies turn to the Systems Engineering (SE) approach, a discipline initially reserved for big defense and aerospace companies. "Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionalities early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem".[2]

According to Wasson [3] "*Unfortunately, the engineering of systems, performed in many organizations is often characterized as chaotic, ineffective, and inefficient. Objective evidence of these characteristics is exemplified by noncompliance to requirements, cost overruns, and late schedule deliveries in program metrics for a project's contract or task triple performance constraints— i.e., technical, cost, and schedule.*". Based on his experience, the author suggest that "*many engineers are estimated to spend on average from 50% to 75% of their total career hours collaborating with others concerning the engineering of systems – i.e., systems engineering - for which they have no formal education*"

Significant efforts are made to improve the discipline of SE, by both industrial and academic players. On the one hand, industries and governments develop standards, norms, competency models, and documentation [4], while applying the SE approach in their projects and promoting it to smaller entities [5] [3]. On the other hand, academic institutions and researchers, most often in collaboration with industries, investigate new paths to teaching SE. They are typically interested in defining *competencies* which best characterize a system engineer, in order to design an efficient *pedagogical model* and an appropriate *learning environment*. In addition to these questions, the present paper particularly focuses on SE standards and on how they can and should be used for SE learning purposes.

The next section of this paper presents a state of the art introducing a number of significant works related to SE education. The following sections convey our own vision of teaching SE, together with a presentation of our developed solution as well as survey results regarding its usefulness and ease-of-use. The paper concludes by highlighting our main contributions and discusses the perspectives of our approach.

Background

Over the last decade, governments, universities, engineering schools and industrial companies have been dedicating much attention to the practice of SE. Various aspects have been addressed including people, processes and technology. In the scope of our study, we are mostly focusing on people and how to make them most efficiently learn the fundamental principles of SE. *"Traditionally, systems engineering competencies have been developed primarily through experience, but recently, education and training have taken on a much greater role"* [6]. The following list compiles a number of significant advances:

Systems Engineering competencies

According to the Systems Engineering Body of Knowledge book (SEBoK) [6], SE competencies reflect the individual's Knowledge, Skills, Abilities, and Attitudes (KSAs), which are developed through education, training, and on-the-job experience. According to the same source, *"For an individual, a set of KSAs enables the fulfillment of the competencies needed to perform the tasks associated with the assigned systems engineering role"*.

A set of SE competencies form a SE competency model which reflects the individual's KSAs. The KSAs are in turn related to different roles in the company or the project, so that they are associated to a set of tasks. A competency model is therefore a framework for organizing a collection of observable KSAs. According to [6], *"SE competency models generally agree that systems thinking, taking a holistic view of the system that includes the full life cycle, and specific knowledge of both technical and managerial systems engineering methods are required to be a fully capable systems engineer"*.

KSAs can be used as learning objectives for SE competency development, especially when they are defined in terms of a standard taxonomy, as in [7]. Authors designed a SE competency career development model as an analytical approach using Bloom's taxonomy. In addition to their use in education, training, and development, competency models can also be used for recruitment and selection, human resources planning and placements [6].

Various competency models exist in the field of SE. Most of them have been developed for specific contexts, since the required competencies can differ between organizations and projects, and they can typically be tailored to the organization or project particularities. The most well-known competency models in the field of SE are:

- INCOSE UK Working Group Competency Model: identifies the competencies required to conduct good SE projects[8].
- Defense Acquisition University (DAU) ENG Competency Model: identifies the competencies required for Department of Defense (DoD) acquisition engineering professionals [9].
- NASA Academy of Program/Project and Engineering Leadership (APPEL): identifies a project management and SE competency model to improve project management and SE at NASA [10].

- The MITRE institute SE competency model: defines new curricula for SE and assesses personnel and organizational capabilities [11]
- INCOSE multi-level professional Systems Engineering Professionals (SEP) certification program: provides a formal method for recognizing the knowledge and experience of systems engineers, regardless of their current point in career [12].

Most organizations tailor those models by including domain-specific KSAs and other particularities of their organization. Also, several models can be used together and merge into a new competency model, as suggested by White [7]

The role of standards in SE education

Some of SE standards describe and provide a framework for system life cycle processes, such as in ISO/IEC/IEEE 15288 [13] or ISO/IEC 20110 [5]. The relation between SE competency models and a system life cycle processes is explained in [6], "SE competency must be viewed through its relationships to the systems life cycle, the systems engineering discipline, and the domain in which the engineer practices systems engineering" [6].

In this paper, we support the use of such SE standards as the basis of a SE education approach, while being in compliance with a SE competency model. As a matter of fact, these standards encompass the fundamental principles of SE which is exactly what we want to teach.

The adequate pedagogical model for SE education

According to Khalaf et al. [14], the nature of the SE discipline is in inherent alignment with the Project-Based Learning (PBL) pedagogy. PBL is especially recommended for developing analytical and problem-solving skills which are necessary to address multidisciplinary and complex engineering problems. According to Dym et al. [1], "*the currently most-favored pedagogical model for teaching Design is Project Based Learning*". Despite the differences between design and systems thinking (a core aspect of the SE discipline) [15], both engineering design and systems engineering mostly deal with processes and skills, and not with transferable and fundamental knowledge. engineering design is defined as "*a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.*" [1]. Therefore, it can be assumed that PBL is actually the most appropriate pedagogical model for both engineering design and SE Education.

Even though PBL seems to be the most adequate model for teaching SE, there are a number of open research questions and challenges regarding this pedagogical model. Some of them have been identified by Dym et al. [1]

Current practices in SE education

Interestingly, current SE education programs do not pay much attention to the design of competency models, nor to the adoption of SE standards. In [16], we surveyed the current practices in SE education published by the European Society for Engineering Education (SEFI), and classified them into 8 categories:

- Master programs with academia-industry partnerships [17] [18].
- Few-months international academia-industry projects [19].

- Student challenges [20].
- Few-weeks projects within regular engineering curriculum [21].
- Theoretical courses within industrial engineering curriculum [22].
- Few-Days Laboratories [23] [24].
- LEGO-Based Programs [25] [26] [27] [14] [28]

Other less prominent SE education approaches exist, some of which can be found in [29], such as Quizzes, Lab Reports, Design Projects, Arduino Projects, Exams, Homework, Labs, Lecture and class discussion, Predominately Exams and a Design Project, Design Challenges, Research Papers, Research Projects, and Case Studies. For a more detailed compilation, IncoSE and the Systems Engineering Research Center (CERC) at Stevens Institute of Technology has published a 116 pages document called *"2016 World Wide Directory of systems engineering and industrial engineering academic programs"* [30]. This report lists the name of universities offering degrees in SE, and provides detailed information. It can be concluded that academia is interested more than ever in SE. However, there is no common teaching model, except for some recommendations and specifications, as highlighted in [16].

Considering the requirements of an efficient learning environment for SE [16], the next sections present our vision of how to improve SE learning experiences by adopting international standards. We are particularly interested in standards concerning the systems life cycle, such as ISO/IEC/IEEE 15288 [13] or the simplified ISO/IEC 29110 [5].

Global proposed approach and its main components

Our vision regarding the best suited environment for teaching SE focuses on new disruptive technologies such as Virtual Reality (VR), Internet of Things (IoT), 3D Printing and Machine Learning, coupled with a Project Based Learning (PBL) model, and a process based learning path. Of course, this vision isn't to be deployed today. However, in this paper, we present our current work results, that might lead to achieving this vision in the future. We aim to make the teaching of SE fundamentals true to reality. Therefore, we promote the learning-by-doing-paradigm, where multidisciplinary students from different locations collaborate to engineer a system requested by an educator, this is what we call a system of interest [13]. Students can adopt different roles such as designer, production operator, requirements engineer, architect or tester. In particular, they are guided to apply SE standard processes and therefore meet situations similar to real-life SE challenges.

Another accordance with real-life SE is the fact that our approach is based on two main components, a virtual and a physical environment, operating through an Internet-of-Thing (IoT) infrastructure. A high level of connectivity between these two environments is needed, not just at the engineering level, but also with respect to the teaching process. The educator is able to track the learning activities inside both the physical and the virtual environments, in order to assist and evaluate students knowledge acquisition.

The global approach will therefore be a domain independent solution used by both educators and students in SE education organizations, enabling a high level of collaboration and interaction.

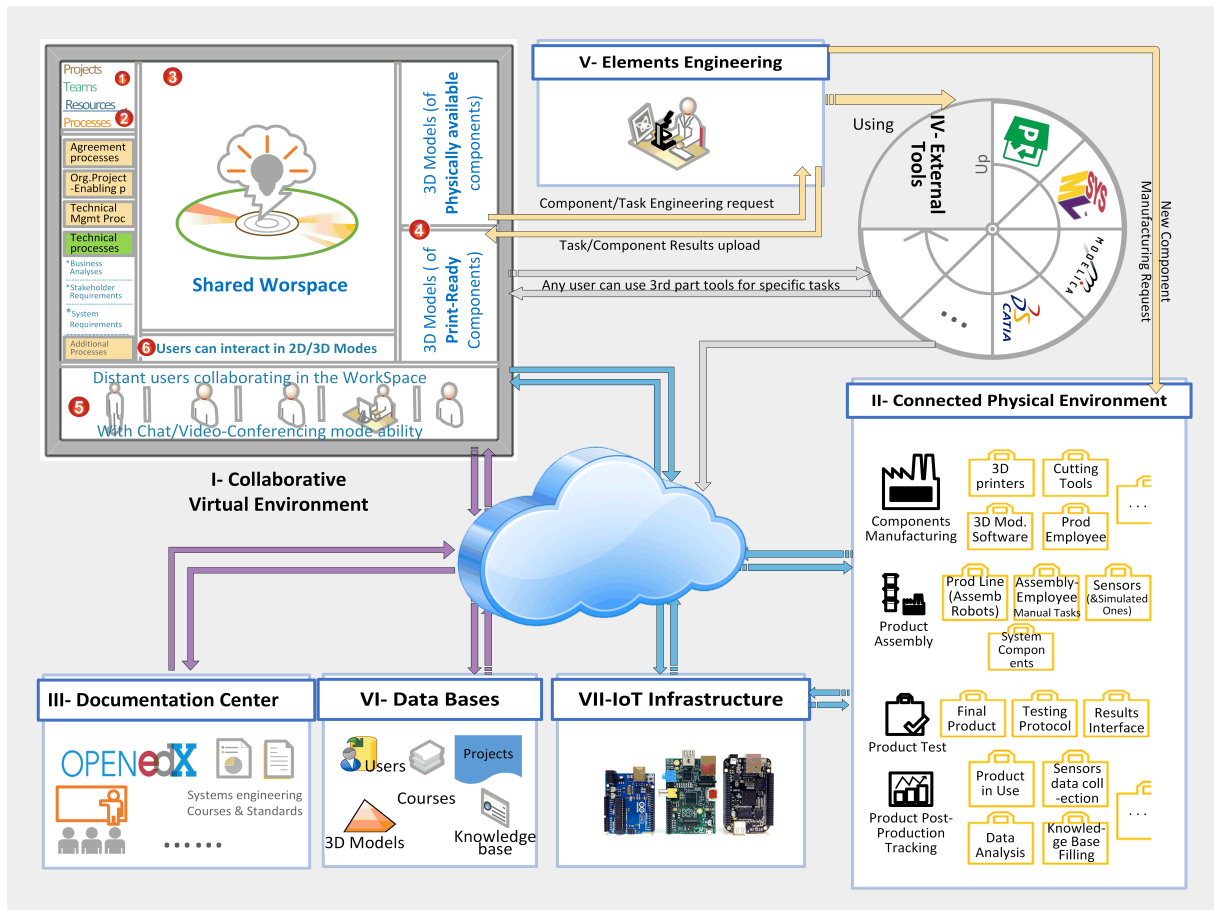


Figure 1: Main components of the proposed SE education approach

Primitive resources

Primitive resources are the atomic components used to create a new system or to modify an existing one. For each primitive resource, students have at their disposal a 3D model inside the *Collaborative Virtual Environment* (CVE), and a corresponding assembly part inside the physical environment. However, in order to satisfy the particular requirements or their mission, they may need additional components. In this case, students design a 3D Model of the missing piece, using the *elements engineering* component of this approach, and they produce the physical unit inside the *physical product assembly environment*, e.g. using a 3D printer.

The collaborative virtual environment

This is the main component of our approach, representing the engineering workspace. It is intended to be a web-based application where students can collaborate, and where they can interact with educators throughout the whole project. Figure 2 show that this environment incorporates several elements, which are:

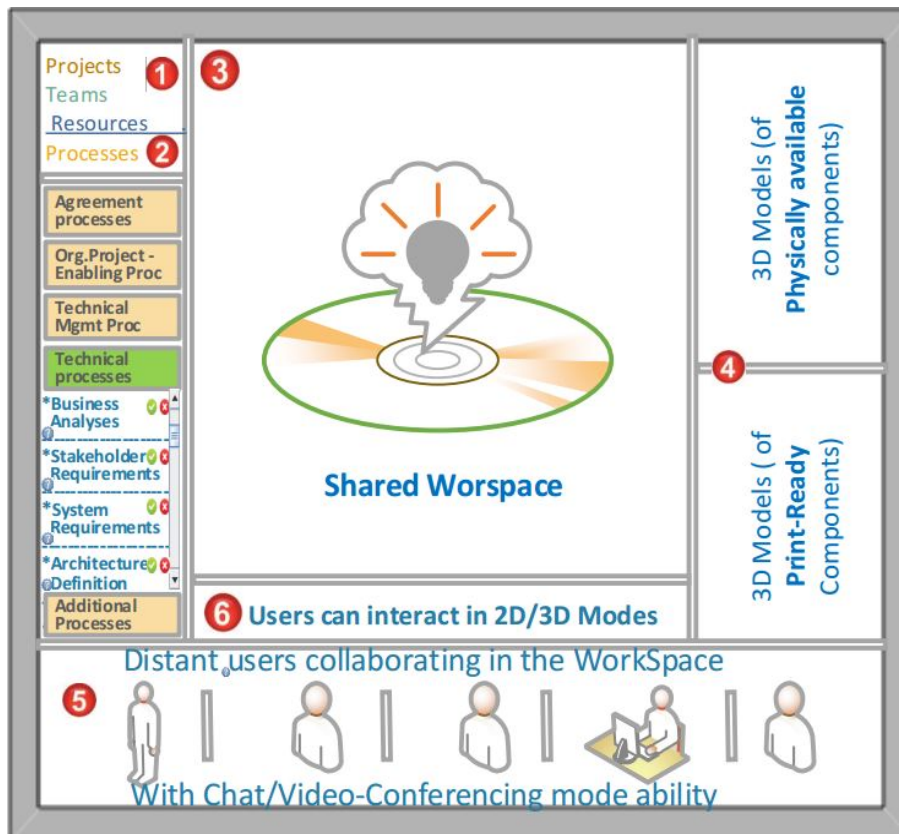


Figure 2: ICVE Elements Description

- **Projects, teams, and resources (1):** The top left part of the screen shows a three-component menu. Its first element, *Projects*, includes a description of the project mission, given out by the educator. By clicking on the *Teams* element, students find information about the other members of their teams co-working on a specific project. They can also manage the different roles assigned to each student during the product. Under the third element of this menu, *Resources*, students find a collection of suggested resources provided by the educator, to guide them through the engineering processes. The educator plays two different roles. First, he can act as the acquirer of the system-of-interest, but another entity can replace this role and define the project mission. Second, the educator plays the teacher role, assisting students throughout the entire process of engineering the system, and evaluating them from an individual and a collective point of view.

Prior to that, students must be recorded in the students data base, with their biography, curriculum and skills. This information helps the educator to efficiently perform student-team-project assignments. A team of students can be responsible of the engineering of an entire system, or their system can be an element of a bigger one. In this case, the educator assigns teams to specific parts of one higher-level project.

- **Life cycle model processes (2):** This is one of the most important parts of the collaborative virtual environment where students follow the life cycle model processes, in order to engineer the requested system. The life cycle model is defined by the acquirer/educator based on the learning goals (SE competencies) and the nature of the system. In addition, for more information about the currently used processes, or for further training regarding

the used resources and methods, students can always access the *Documentation Center* which may be a LMS or a MOOC platform.

- The shared workspace **(3)**: Represents a virtual place where students can report the results of their performed tasks. All team members, including the educator, have a complete overview of their progress at any time, and they are able to annotate and exchange work.
- 3D virtual models **(4)**: The shared workspace gives access to the 3D models that can be used as primitive elements in the design process. These models may already exist in the physical world, or they can be 3D-printed to assemble the final system-of-interest. As illustrated by **(6)**, students are able to interact with the shared workspace, both in 2D and 3D modes, depending on the nature of their task.
- Collaboration **(5)**: Using the collaborative virtual environment, students and educators can communicate and exchange through a chat or video-conferencing system.

The physical environment

The Physical Environment represents the traditional manufacturing factories and production lines for assembly. We distinguish the *Manufacturing Environment* with activities relative to new components production, using tools and machines such as 3D printers, and the *The Assembly Environment*, which may include a robot based production line for components assembly, with the help of an *assembly operator*. Moreover, we assume that all components contain sensors that allow a real-time tracking of the assembly operations, reporting relevant data to the CVE through an adequate IoT architecture. The physical environment includes a *testing environment* where the operator can perform a series of test procedures on the assembled system-of-interest, and report the results to the CVE. This approach is particularly interesting if the IoT infrastructure allows a post-production tracking of the system-of-interest, allowing for additional tests to be directly performed from within the virtual environment.

Learning and documentation center

The documentation center is a virtual space where students have easy access to educational resources, such as documents and videos, online libraries, LMS and MOOC platforms, etc. By this means, students can find the appropriate time to learn more about different aspects of the SE discipline, including its standards, processes, methodologies, and also consult useful information and tutorials about SE related tools.

System elements engineering

This part of the global vision is related to a scenario where students are asked to design a required component for the system-of-interest, which turns out to be so complex in itself that it needs collaboration between different students in the team or between the different teams. In that case, the component can be considered as a new system-of-interest, and students have to engineer it by applying the same SE life cycle processes as for the higher-level system-of-interest. After performing each task, the outcomes are uploaded to the collaborative virtual environment.

Third-party tools and resources

A good SE learning solution should be highly tool-independent, so that every organization, educator and student can choose the most adequate tool for their SE activities. Ideally, students should be able to access their tools directly inside the collaborative virtual environment. Otherwise, they may resort to external tools and upload the results.

Implementation

After the previous discussion of our global solution for SE education, this section presents our progress concerning its implementation. In the scope of this paper, we propose a solution for teaching SE, which promotes the use of SE international standards and allows students to learn through a project-based learning approach.

At its current stage, the solution allows working with only one kind of processes, the technical processes, where students can engineer their systems without dealing with other activities related to management, agreement, or project-enabling processes. Students can be asked to use the technical processes of a given standard, such as the ISO/IEC/IEEE 15288 [13], or the ISO/IEC 29110 [5]. However, educators are free to define other process flows, by adding new unstandardized processes, or by inserting processes from other standards. Two use-cases applying our solution are described in [31].

In this solution, students and educators pass through well-defined scenarios. The reader can find the most important components of the solution in Appendix A.

- Main learning scenario

This represents the high-level learning scenario. As illustrated in Figure 3, it encompasses other sub-scenarios. The proposed solution has two main players. On the one hand, educators are responsible for creating projects, by defining their goals and life-cycle models. They also assign student teams, ensure assistance and assessment. Students, on the other hand, are responsible for collaboratively engineering the system, with respect to the processes defined by the educator.

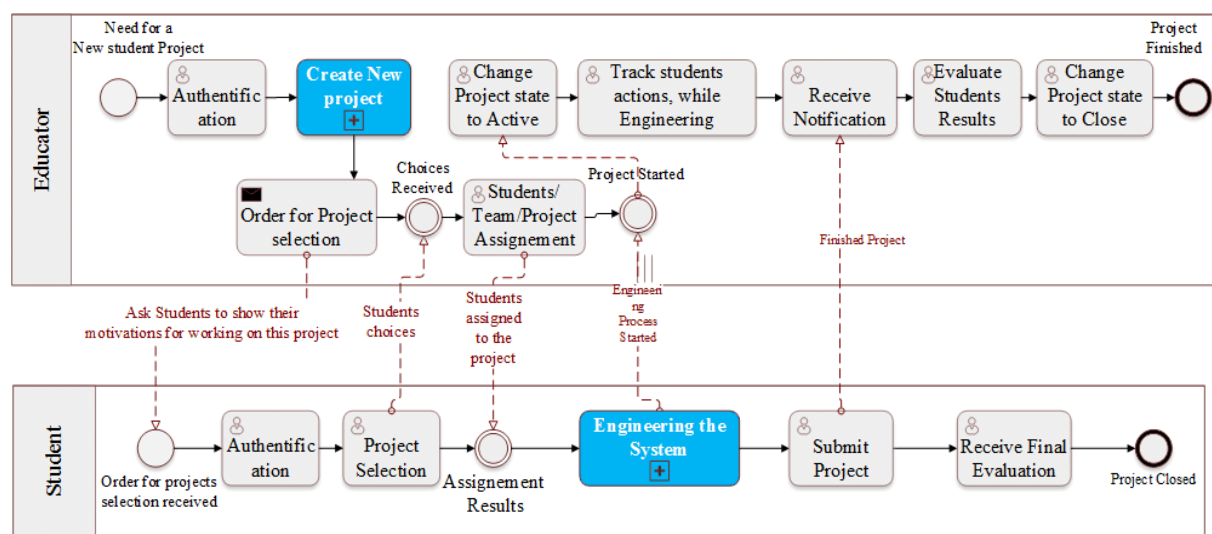


Figure 3: Global Learning Scenario

Note that it is possible to extend the use of standard processes even to the definition of the mission objectives. As a matter of fact, the solution may implement the acquisition process, the first process of the ISO/IEC/IEEE 15288 agreement processes, where educators and students can negotiate and agree on the work to be done.

- Educator: Project creation scenario

As illustrated in Figure 4, creating a new project goes through several stages. The educator defines the project title and description, as well as the life-cycle model which will be followed by students. For this purpose, the educator selects a number of processes from the processes database. If a specific process does not exist in the database, it can be added using the processes management system, as illustrated by Figure 5. Finally, the educator specifies the resources and tools to be used by students.

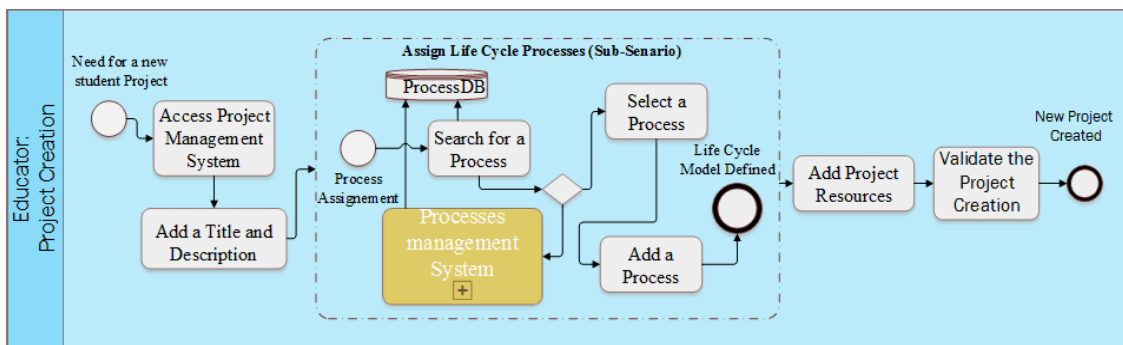


Figure 4: Project creation scenario

For the time being, the life-cycle model is defined by the educator. In the future, it may be possible that students with a solid background in SE are asked to define the life-cycle model by themselves.

- Educator: Processes management scenario

This scenario allows educators to create, adapt or remove SE processes. The adopted architecture for a process is compliant to the 15288 standard. In addition to its purpose and its outcomes, a process is defined as a set of activities, and each activity is defined as a set of tasks to be performed.

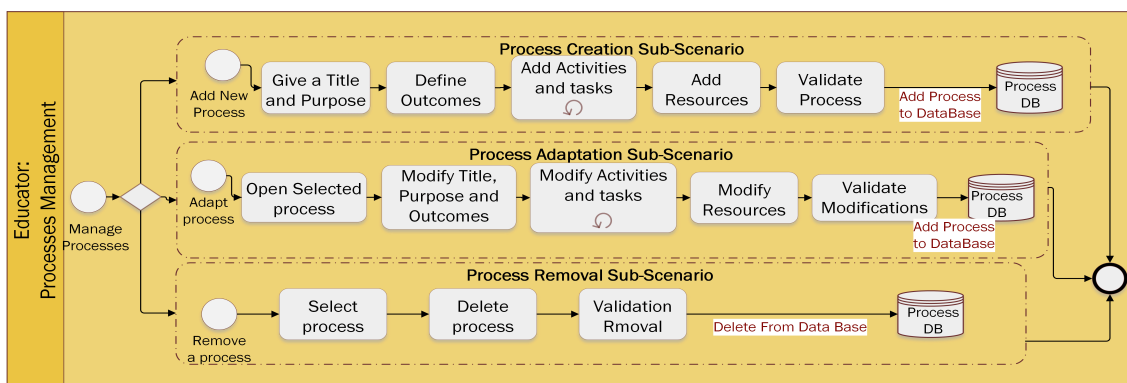


Figure 5: Processes management scenario

- Student: Project engineering scenario

This scenario, described in Figure 6, represents the high-level stages that students will follow to engineer the required system. After selecting an active project, and after managing their roles, students engineer the system by performing the tasks of each activity of the life-cycle model processes. The tasks are done using the adequate tools and methods, and their results are uploaded to the project work-space.

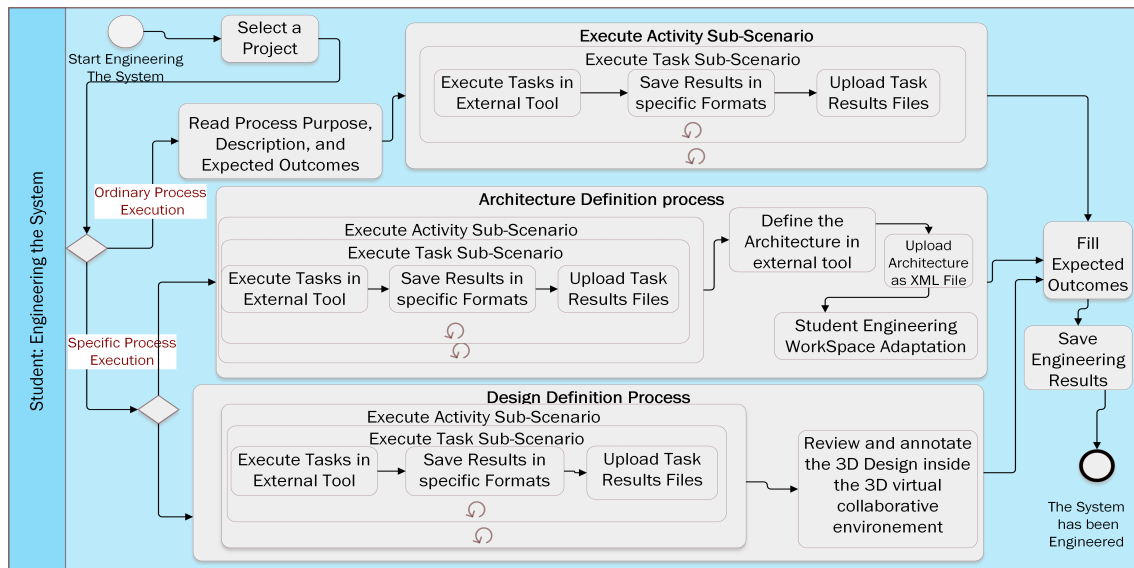


Figure 6: Project Execution scenario

All processes are executed in the same way, except for the *system architecture definition process* and the *system design definition process*, which include some specific tasks that can be executed inside the solution, as described next.

- Student: Environment Adaptation According to System Architecture Scenario

The system architecture is defined by students and uploaded to the project workspace in form of an xml file. Depending on the chosen architecture, the project workspace is automatically adapted to provide students sub-workspaces for each subsystem or system element. Consequently, students can engineer each subsystem and system element as a system, by passing through the entire life-cycle model.

- Virtual design scenario

Virtual 3D representation and the design of a tangible system are indispensable in any system design process. In our solution, we propose virtual system assembly in a collaborative mode, where students in different locations are able to visualize and interact with the system being assembled in real time. Currently, the virtual design is possible for a limited number of pieces. If users want to use the 3D features, they can only engineer systems based on the LEGO® MINDSTORMS® Education EV3 Bricks and their additional elements (Sensors, Motors...etc). However, if 3D virtual design is irrelevant for students and educators, the solution can be used to engineer any kind of systems. The 3D visualization can also be used for simple design review instead of system assembly.

- Collaboration

Collaboration is enabled and encouraged in this solution, allowing students to work together on different tasks of the same project, while maintaining a global vision of the work all along the engineering scenarios. More features are planned to enhance collaboration, such as annotation of results, or chat and video-conferencing.

- Assessment

Student assessment is out of scope of this paper. However, we profoundly believe that this solution will help implementing new students assessment methods, allowing educators to objectively evaluate students with respect to various teaching objectives. We already identified a number aspects that need to be considered for assessing students in a SE learning experience as: *result assessment*, *execution assessment*, *knowledge assessment*, and *skills assessment*.

Results and discussion

In this section, we discuss the acceptance of our solution by the SE academic community. We targeted a specific public within this community with a presentation of the solution and a survey.

Methodology

The targeted public were students and tutors participating in the 2016 Robafis challenge. Organized since 2006 by AFIS, the French chapter of INCOSE, the Robafis challenge is a yearly student competition for robot design [20], whose main goal is the promotion of SE. About ten student teams from French universities and engineering schools participate in this competition. Each team can consult a SE teacher, and they can also question AFIS experts. The road-map starts about eight months before the final stage competition, when AFIS communicates the general schedule, the regulations, specifications, and a reference development document. Three months before the final stage, the teams register and receive a LEGO Mindstorms Robotics kit, in order to physically implement their solution. Fifteen days before the final stage, the teams send their development document to systems engineering experts for evaluation. The competition concludes by a final stage where all teams meet and operationally validate their works, along with project and configuration audits. Few weeks after the competition, students receive a detailed debrief regarding their work.

In 2016, eight student teams participated in the Robafis challenge. Some mixed teams featured students from several engineering schools. We got in touch with four teams, totaling in 25 students and 9 tutors. The tutors are mainly educators in the field of SE. Since the solution was not shared for public, we produced a video tutorial showing the platform at work and explained its most relevant features. The video was shared with our targeted public, together with a questionnaire they had to answer. The video can be viewed here [32], and the questionnaire used for the educators can be found in appendix B. Note that there are not many differences between the two questionnaires, as we were mainly interested in feedback regarding the implemented/to-be-implemented features of the solution. The few differences will be apparent during the result analysis.

We received responses from ten students and six tutors, which represents a response rate of respectively 40% and 66%. The feedback from both students and tutors showed a high interest in the features of this solution.

Respondents profile

Nine out of ten of students who answered this questionnaire are undergraduate students, whereas the last one is a post-graduate student. 70 % of students estimate that they are beginners in SE, and the most usual way of learning SE were university lectures for 70%, and academic project-based learning for 60%. It appears from their responses that most of them have an overview of different topics of SE, with a focus on three topics, for which more than 90% think that their level is between medium and good: *"Design, Analysis, and Implementation"*, *"Operation and Management"*, and *"Technical Management"*. Also, 80% think they are good, or at least having a medium level in *"Requirements Management"*, *"Architecting"*, and *"Project-Enabling Management"*.

Tutors respondents are mainly academic SE practitioners, exercising in this fields for more than two years for 67% among them, and more than five years for 17%. 50% used to teach and promote SE through *"university lectures"*, *"competitions and challenges organization"*, and *"academic or academy-industry project-based learning"*.

Results from the students perspective

The following list itemizes the received student feedback concerning

- The usefulness of the current features of the solution: The two features that appear not to be very useful, from a students perspective, are *"the ability to add resources to different processes"*, and *"reviewing the 3D design of the system"*, where only 50% estimate that they are useful or necessary. All the other features are considered useful by at least, 60 to 70% percent. For details, please refer to Table 1.

Table 1: Students appreciation about current features usefulness

Current features usefulness	Mandatory %	Very Useful %	Useful %	Not very interesting %	Needs Improvements %	Not useful at all %
Enabling geo-distributed students to work together	10	10	50	10	20	00
Learning through SE processes	10	50	00	10	30	00
Reporting all tasks results in the same shared space	10	40	20	10	20	00
Virtual 3D design of the system	00	30	20	10	30	10
Processes presentation	10	30	30	10	20	00
Processes related resources	10	20	20	30	20	00

- The ease-of-use of the current features: Most features are considered simple or very simple to use. About 70% to 90% of students share the same opinion about all features,

except for the "virtual 3D design component", where only 50% think that it is simple to use, while the other 50% rate this feature to be hard or very hard. See table 2.

Table 2: Students appreciation of current features ease-of-use

Current features ease-of-use	Very simple %	Simple %	Pretty hard %	Very hard %
Enabling geo-distributed students to work together	10	60	30	00
Reporting all tasks results in the same shared space	30	60	10	00
Reviewing the 3D design of the system	00	50	40	10
Notification management system	10	60	30	00
Processes presentation	20	50	30	00

- The additional features to be implemented: Table 3 shows that the suggested features which we plan to add to this solution, will be very useful, if not obligatory, except maybe the chat and video-call systems.

Table 3: Students appreciation of additional features usefulness

Additional features usefulness	Mandatory	Useful	Not Useful
Chat system	40	20	40
Video-call system	10	40	50
Assisting student through annotations	30	60	10
Engineering at both system and subsystems level	30	70	00
Tasks management	50	40	10
Direct web-access to SE tools	20	70	10
Direct web-access to learning resources and platforms	10	70	20
Downloading a project synthesis, at any moment	50	50	00

- Students evaluation methods: Students think that they should be evaluated in the context of learning SE, using different methods at the same time. 50% of students agree on evaluating them by the educator throughout the project (evaluation of processes execution quality), and regarding the acquired skills and knowledge (using questionnaires, for example). However, only 40 % of the respondents approve of self evaluation methods and final results evaluation. Regarding peer evaluation techniques, only 30% believe that this is a good way of evaluation.
- Advantages of this solution compared to their traditional way to learn SE: The ease of use, the implementation of the project-based learning approach, and the use of SE standard processes are the most appreciated features of this solution (respectively by 50%, 50%,

and 40% of the responses), followed by the ability to evaluate students regarding different metrics (30%).

Results from the educators perspective

- Current features usefulness and ease-of-use: Educators think that all features are useful without any exception. However, they showed a special interest in the processes, life cycle and projects management systems, the ability to learn through real SE processes, and the ability to supervise students performing tasks in one shared space. See table 4. Educators are also unanimous about the ease-of-use of the current features, see Table 5.

Table 4: Educators appreciation about current features usefulness

Current features usefulness	Mandatory %	Very Useful %	Useful %	Moderately useful %	Not useful at all %	Need Improvements %
Processes management system	16.66	33.33	50.00	00.00	00.00	00.00
Adding resources to processes	00.00	50.00	50.00	00.00	00.00	00.00
Projects creation and management	16.66	50.00	33.33	00.00	00.00	00.00
Life-cycle model definition	00.00	50.00	50.00	00.00	00.00	00.00
Notification management system	00.00	00.00	83.33	16.66	00.00	00.00
Enabling the use of SE processes	00.00	50.00	33.33	16.66	00.00	00.00
Reviewing the 3D design	00.00	16.66	66.66	16.66	00.00	00.00
Supervising one shared space	16.66	33.33	50.00	00.00	00.00	00.00
Enabling distributed engineering	00.00	33.33	66.66	00.00	00.00	00.00

Table 5: Educators appreciation of current features ease-of-use

Current features ease-of-use	Very simple %	Simple %	Pretty hard %	Very hard %
Processes management system	16.66	50	33.33	00.00
Adding related resources to processes	16.66	50.00	33.33	00.00
Projects creation and management	16.66	83.33	00.00	00.00
Life-cycle model definition	16.66	50	33.33	00.00
Notification management system	16.66	50.00	33.33	00.00
Reviewing the 3D design of the system	33.33	33.33	33.33	00.00
Supervising one shared space	33.33	33.33	33.33	00.00
Enabling distributed engineering	66.66	16.66	16.66	00.00

- **Additional features usefulness:** Regarding the proposed additional features, educators mostly agreed on their utility. According to their responses, the most important extensions are assisting students throughout the execution of SE processes, the ability to consider and engineer subsystems as a system, and students managing their tasks.

Table 6: Educators appreciation of additional features usefulness

Additional features usefulness	Mandatory %	Useful %	Not Useful %
Chat system	00.00	83.33	16.66
Video-call system	00.00	83.33	16.66
Assisting student through annotations	33.33	66.66	00.00
Engineering at both system and subsystems level	33.33	66.66	00.00
Tasks management	16.66	83.33	00.00
Direct web-access to SE tools	33.33	50.00	16.66
Direct web-access to learning resources and platforms	33.33	33.33	33.33
Downloading a project synthesis, at any moment	16.66	50.00	33.33

- **Students evaluation methods:** Educators also believe that students should be evaluated in the context of learning SE, using different methods and metrics at the same time. The most expected method by educators is the ability to assess students throughout the project execution process (the engineering of the system), recommended by about 83% of them. This mainly represents the evaluation of SE processes execution quality. The second method favored by about 67% is student evaluation regarding the acquired knowledge and skills, by using surveys at the end of the project, but also by extracting useful information from the learning process. The third method recommended by 50% of educators, was self-evaluation and evaluation of the final results in order to see if they match with the starting requirements. Just as students, only 33% of educators approved of peer evaluation.
- **The advantages of this solution compared to their traditional way to teach SE:** Unlike students, educators did not think that the ease-of-use and the project-based learning approach were the most important aspect that differentiate this solution from traditional SE teaching. However, 50% of educators appreciate the use of SE standard processes and the ability to evaluate students using different metrics. More importantly, about 67% declare that the ability to manage the systems life-cycle model is a good idea, along with the ability to manage geo-distributed students.

Conclusion

In this paper, we presented a solution for SE education, using international standards in a project-based-learning approach. Thanks to this concept, students will learn to not only engineer the requested system, but also to engineer it the right way, using real-life SE practices conveyed by standardized processes, together with communication, team management, collaboration and related soft skills. The main advantages of our solution are the processes, life-cycle, and projects

adaptation and management components, as well as the shared workspace for students engineering tasks during all the life cycle. Another advantage of the solution resides in its ability to help in meeting the challenges of a project-based-learning approach, in particular by opening a way of assessing students by different metrics, including: the final results, the execution quality, the acquired knowledge, and the acquired skills. In addition, the conducted survey highlights that both educators and students appreciate the usefulness and the ease of use of the current features of the solution. They also approved the proposed additional features, except for the chat and video-call systems.

These additional features will soon be added to the solution. After their implementation, we intend to conduct two new experimentations. The first one will consist of a survey targeting a larger amount of potential users. The second one will be the application of the solution to actual SE teaching. For this purpose, we aim to propose a SE course for a large group of students. Students will first assist to theoretical lectures on SE, and will then be asked to engineer a system in small groups. Half of these groups will be using our solution, and the other groups will work in a traditional fashion. At the end of the course, their results will be compared, with a special focus on the quality of the final product and its conformance to the project requirements, the acquired knowledge and skills, and the quality of SE processes execution.

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Appendices

A Appendix A: An illustration of some features from the proposed solution

- Educator: Processes activities and tasks definition

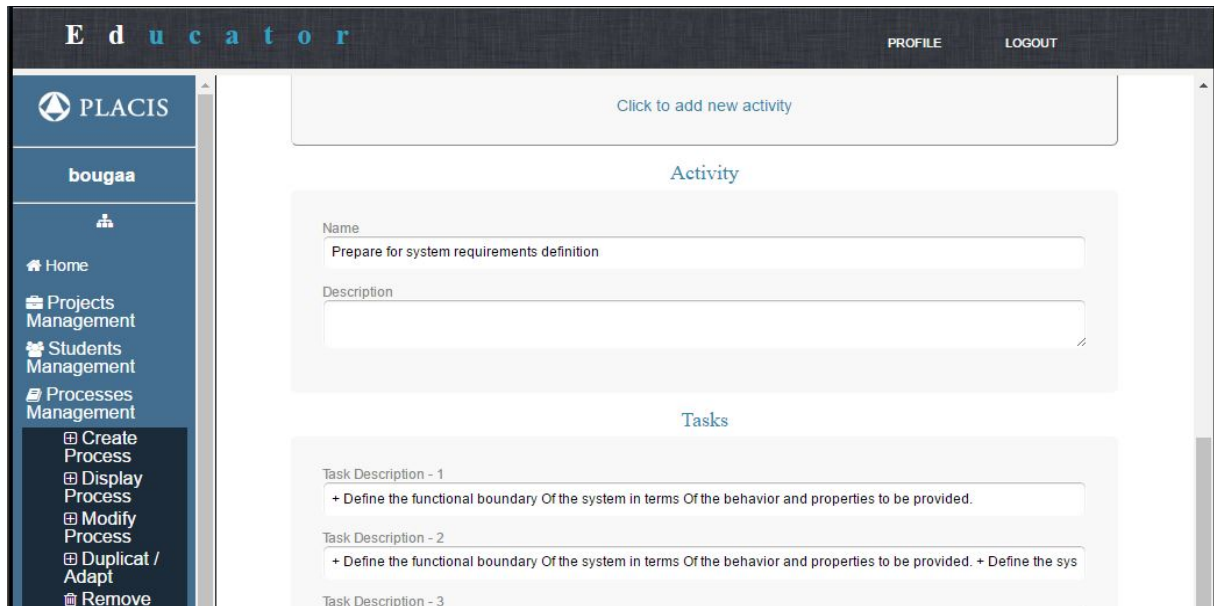


Figure A.1: Adding activities and their related tasks to a specific process

- Educator: New project definition

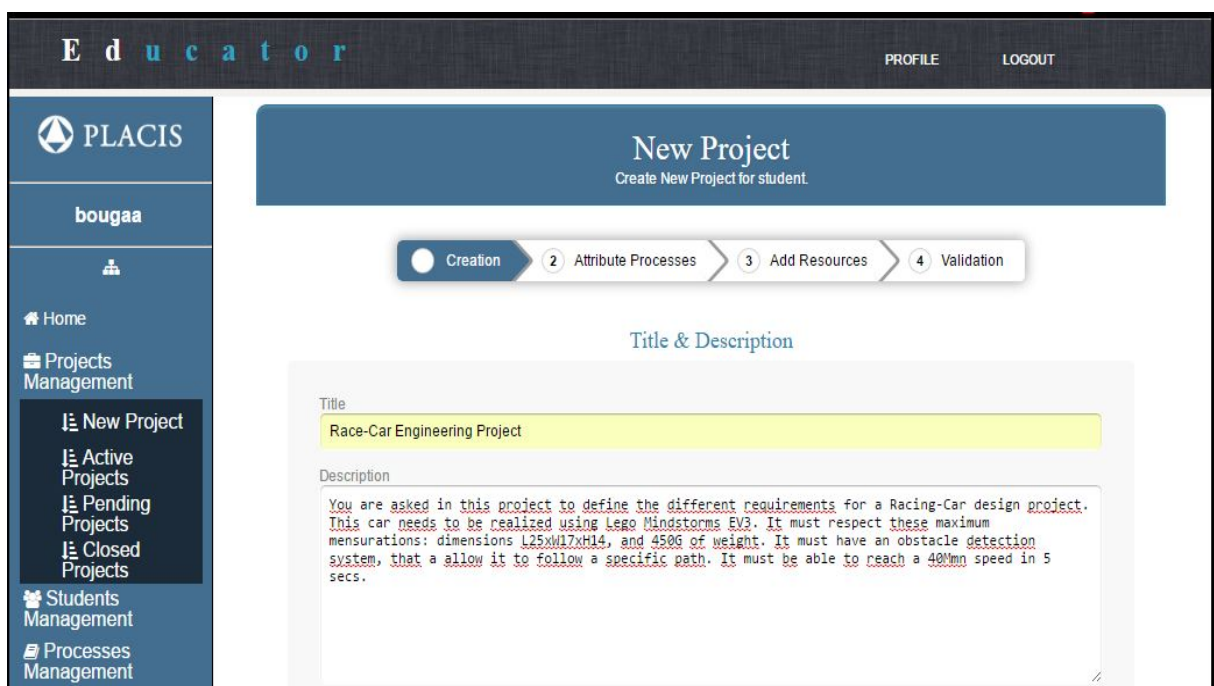


Figure A.2: Adding a title and a description of a new project

- Educator: Life cycle model definition (Processes attribution)

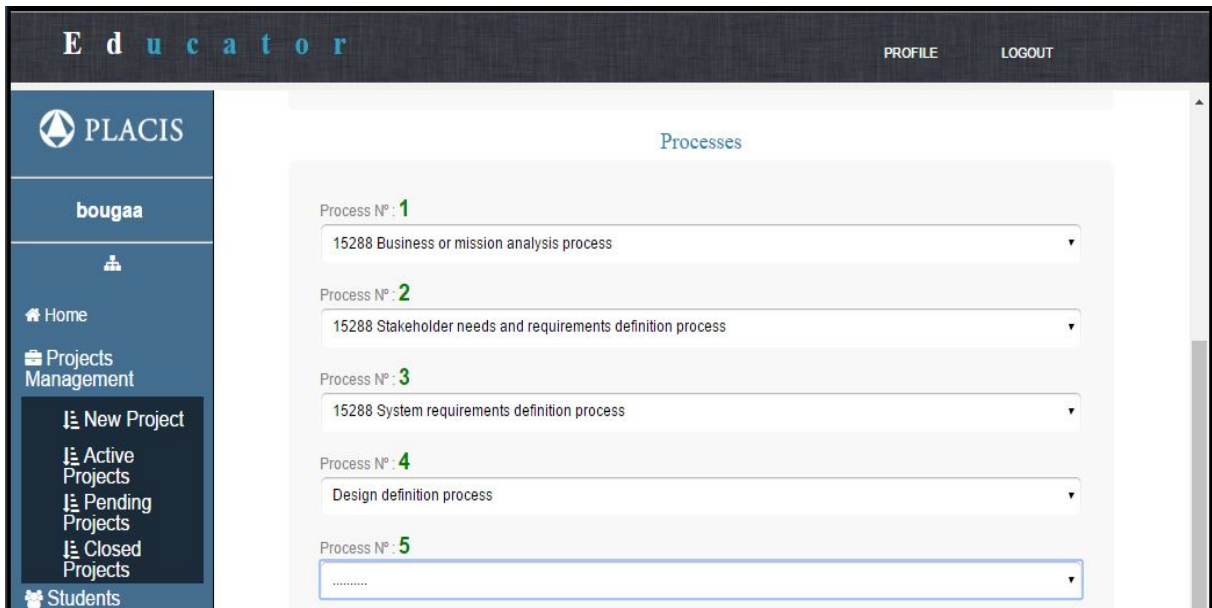


Figure A.3: Defining the adequate Life-Cycle Model for this project

- Student: A project workspace for a specific team

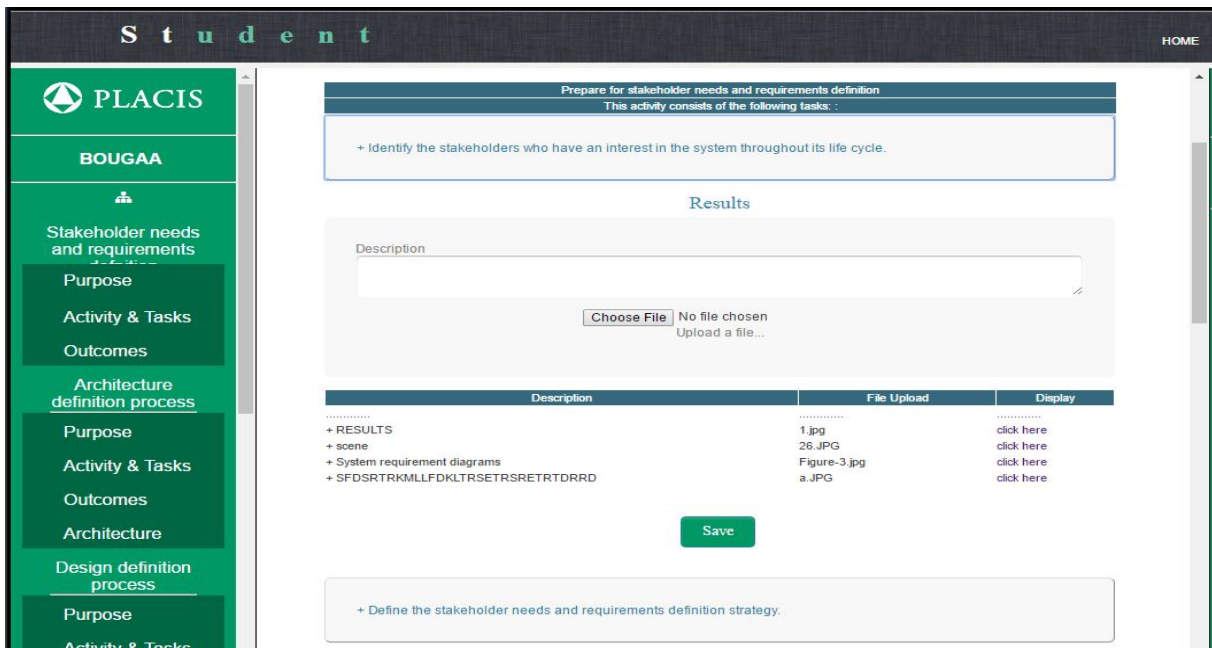


Figure A.4: A task execution results upload, relative to the first activity of the *Stakeholders needs and requirements definition* process

- Student: Architecture definition process

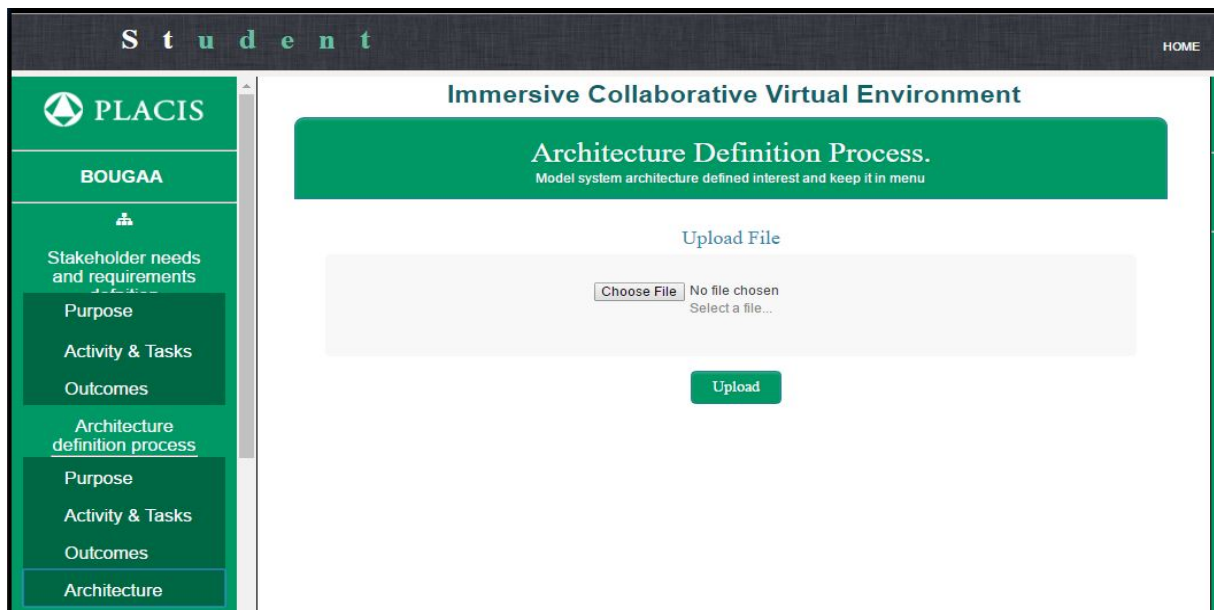


Figure A.5: System-of-interest architecture upload, as an XML file

- Student: 3D Design review and assembly feature, only supporting Lego Bricks for now.

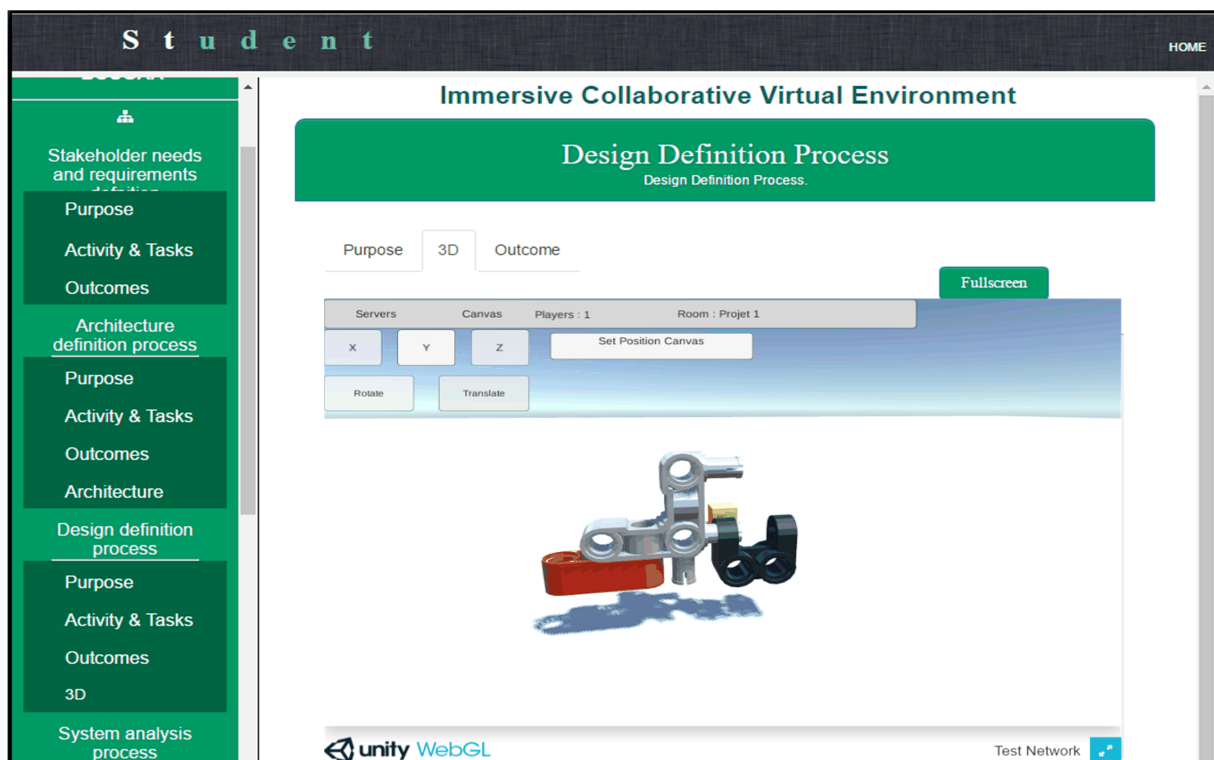


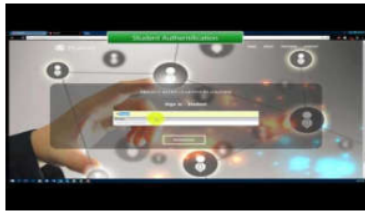
Figure A.6: a collaborative virtual 3D environment for virtual design review and assembly

B Appendix B: Educators Questionnaire

Evaluation of a new solution for Systems Engineering Education

*Obligatoire

1. Adresse e-mail *



<http://youtube.com/watch?v=ANv67Jxy3fo>

Some information about you

These information will only be used for statistical goals, and will be treated anonymously.

2. You are: *

Une seule réponse possible.

- Industrial Systems Engineering Practitioner
 Academic Systems Engineering Practitioner
 Both Industrial and Academic Systems Engineering Practitioner
 Autre : _____

3. How much experience you have in Systems Engineering field *

Une seule réponse possible.

- Less than 1 year
 2 to 5 years
 More than 5 years

4. How you used to transfer Systems Engineering knowledge and skills *

Plusieurs réponses possibles.

- I dont teach Systems Engineering
 Systems Engineering university lectures
 Systems Engineering Books
 Using MOOCs (Massive Open Online Courses, ex.Coursera, Edx...etc)
 E-learning plateformes (Other than MOOCs)
 Academic Project Based learning
 Industry-Academy Project Based learning
 Competitions and challenges organization
 Autre : _____

5. What are the topics/processes you deal with the most in Systems Engineering *

Une seule réponse possible par ligne.

	All the time	Occasionally	Rarely	Never
System & Stakeholder Requirements	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Architecturing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design, analysis and implementation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Integration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Test, verification and Validation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Operation and Maintenance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Technical management (project planning & assessment, decision & risk management ...etc)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Acquisition and Supply	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project-Enabling Management (Life Cycle Model, Infrastructure, Portfolio, Knowledge...etc)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

What do you think about the actual features of the proposed solution

6. Please give your opinion about usefulness of these features *

Une seule réponse possible par ligne.

	Obligatory	Very Useful	Useful	Moderately Useful	Not useful at all	Need Improvements
Processes Management System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adding related resources to processes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Projects Creation and Management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Life Cycle Model Definition	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Notification Management System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enabling learning by executing the real Systems Engineering Processes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reviewing the 3D Design of the System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supervising all tasks results in the same shared space	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enabling Geodistributed students to work together	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. Please give your opinion regarding the ease-of-use (the ergonomy) of these features *

Une seule réponse possible par ligne.

	Very simple to use	simple to use	Pretty hard to use	Very hard to use
Processes Management System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adding related resources to processes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Projects Creation and Management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Life Cycle Model Definition	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Notification Management System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reviewing the 3D Design of the System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supervising all tasks results in the same shared space	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enabling Geodistributed students to work together	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

What do you think about the following additional features:

These are some additional features we think useful to improve this solution, please tell us what do you think

8. Enabling students in the same team to communicate in real time, by adding a chat system *

Une seule réponse possible.

- Necessary
- Useful
- Not Useful
- Autre : _____

9. Enabling students in the same team to communicate in real time, by adding a video-calling system *

Une seule réponse possible.

- Necessary
- Useful
- Not Useful
- Autre : _____

10. Allowing educators to assist students by making notes about the tasks being realized durring their execution. *

Une seule réponse possible.

- Necessary
- Useful
- Not Useful
- Autre : _____

11. Allowing students to Manage and execute the processes of the Life Cycle Model on the full system, but also on its sub-systems and systems elements. In other terms, adding a feature that allows students to switch between the different sub-systems and systems elements. *

Une seule réponse possible.

- Necessary
- Useful
- Not Useful
- Autre : _____

12. What about adding a features that enables students to manage and assign the different tasks to the different students of the team. *

Une seule réponse possible.

- Necessary
- Useful
- Not Useful
- Autre : _____

13. **Would it be better if it's for the Educator himself to manage and assign the different tasks to the different students of the team. ***

Une seule réponse possible.

- Yes
 No
 Autre : _____

14. **What about adding a feature that enables students getting direct web-based access to systems engineering tools (such as SysML) ***

Une seule réponse possible.

- Necessary
 Useful
 Not Useful
 Autre : _____

15. **What about adding a feature that enables students getting direct web-based access to documentation and learning platforms such as EDX. ***

Une seule réponse possible.

- Necessary
 Useful
 Not Useful
 Autre : _____

16. **What about giving the the Educator the ability to download at any time, a synthesis of the project as a Pdf File. ***

Une seule réponse possible.

- Necessary
 Useful
 Not Useful
 Autre : _____

17. **What do you think will be the best way to evaluate the work done under this solution? ***

Plusieurs réponses possibles.

- Self Evaluation (By taking a survey)
 Peer Evaluation (Evaluation of the results by other students)
 Educator evaluation regarding the final Results
 Educator evaluation throughout the project execution
 Educator evaluation regarding the aquired skills and Knowledge (using questionnaires and projects execution data)
 A mixture of some of the previous methods (please check the ones you think are the best)
 Autre : _____

Comparing this solution

18. **In which way do you think this solution is BETTER than the solutions you used to know or to teach systems engineering with (especially after adding the additional features). ***

Plusieurs réponses possibles.

- The ease of use of the solution
 The management of Geodistributed students
 The management of a Project Based Learning approach
 The use of Systems Engineering Standard Processes
 The ability to manage the Life Cycle Model
 The ability to use any Systems Engineering Standard (Standard choice independant)
 The ability to use any Systems Engineering Tools (Tools choice independant)
 The ability to evaluate students regarding different Metrics
 Autre : _____

19. **Do you have any additional remarks or suggestions?**

Une copie de vos réponses sera envoyée par e-mail à l'adresse indiquée.