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How to efficiently handle 300 projects on Model Representations and Analysis?

C. Stoica Maniu* V. Letort-Le Chevalier** G. Sandou*
H. Lhachemi* S. Font* C. Vlad*

* *Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des signaux et systèmes, 91190, Gif-sur-Yvette, France*
(e-mail: {cristina.stoica; guillaume.sandou; hugo.lhachemi; stephane.font; cristina.vlad}@l2s.centralesupelec.fr)

** *MICS - Mathématiques et Informatique pour la Complexité et les Systèmes, CentraleSupélec, 8-10, rue Joliot Curie, 91192 Gif-sur-Yvette, France*
(e-mail: veronique.lechevalier@centralesupelec.fr)

Abstract: The current international trend of grouping together several engineering institutions leads to large-scale student classes. This raises numerous challenges for spreading the engineering science at a broad range but also offers the opportunity to build the premises for up-to-date educational innovations. The aim of this paper is to propose a modular and easily extendable database, with a user-friendly interface, allowing to handle a multitude of student projects in the field of engineering. In order to demonstrate the efficiency of the proposed framework, a case study on the implementation of the database for handling 300 projects in the context of the course *Model Representations and Analysis* given at CentraleSupélec to 900 students during the school year 2021-2022 is reported.

Keywords: Control education, Teaching aids for control engineering, Challenges for control engineering curricula, Internet-based control systems materials, Open educational resources, Blended learning in control.

1. INTRODUCTION

The economic model of engineering institutions needs to adapt to the current international demands. This includes competitiveness, visibility (both with respect to funding agencies and students), employability of the students after graduation, etc. These different criteria are evaluated on a regular basis through the publication of academic rankings for universities around the world (Liu and Cheng, 2005), among which the famous *Shanghai ranking*. In this context, there is an actual international trend of grouping together several universities and graduate schools to reach a higher international level of visibility. A side effect of such a trend is that more and more students are enrolled each year in engineering teaching modules. Thus the teaching teams have to adapt their pedagogy, content, and teaching tools (assessment, online teaching, etc.) to these new requirements.

The new curriculum of CentraleSupélec¹ was developed in a modular configuration (see Jankovic et al. (2019)). Originally designed for approximately 800 students per year, the scalability of the teaching process has allowed the increase of the number of enrolled students. For the school

year 2021-2022, approximately 900 students are registered for the first year of the CentraleSupélec curriculum. This high level of flexibility is challenging for core courses: it requires the deployment of procedures, especially for traditional on-campus learning, in order to help professors to deal with the increasing workload. This is all the more required to allow professors to propose and manage learning activities that are off the beaten track at nearly individual student scale.

The syllabus of the *Model Representations and Analysis* core course contains three parts: (I) continuous-state system modeling and analysis; (II) discrete event system modeling and analysis (this part is essentially based on the textbook of Cassandras and Lafortune (2008)); and (III) model identification, uncertainty propagation and sensitivity analysis of the proposed models. We refer the interested reader to Stoica Maniu et al. (2019a, 2020, 2019b) for more details about the content of the course. One conference given by Varenne (2018) on the epistemology of models, mainly covering the diversity of model functions and model types, concludes this module. There are 36 on-site hours (15h of lectures, 15h of tutorials, 1.5h of conference, 1.5h of Q&A session on the projects, and 3h of exam) for an estimated total student workload of 60h.

During the previous three occurrences of this course, student projects covering parts I and II were deployed. The main objective of these projects is to improve the insight of the students into the practice of system modeling

¹ CentraleSupélec is one of the most prestigious French graduate engineering schools, called “Grandes Ecoles”. CentraleSupélec has a three-year curriculum, preceded by two intensive years of higher education in the so-called “Classes préparatoires”. This system of education is quite specific to the French teaching system.

and simulation beyond the simple exercises encountered during the tutorials. In the initial setup, each group of 3 students² proposed a subject for a project and then solved a subject proposed by another team (such an assignment was performed randomly). In this process, the pedagogical team provided detailed instructions to better frame the subjects proposed by the students to make sure that the topics proposed by the students are well suited with the pedagogical content of the course. For instance, one of the main instructions was that only modeling problems that are tractable using Ordinary Differential Equation (ODE) models are allowed. Despite these detailed instructions, each year projects that did not frame with the content of the course were proposed by students. Typically, problems that inherently require the development of models using Partial Differential Equations (PDEs) were proposed each year by a significant amount of groups that fell outside the scope of the module and project objectives. This resulted in a very time consuming effort from the teaching team to answer students' questions and to adapt and reformulate the subject to better frame the pedagogical objectives of the course.

Moreover, after just three occurrences of the course, a database circulated among the students. This database included the subjects proposed during the previous years as well as their resolution. Hence, as a matter of fact, a very significant amount of students used the database to lower their workload by picking and slightly reformulating a subject from the database with very few new elements. This state of affairs was corrupting the original spirit of the subject research activity.

To overcome all these difficulties, the teaching team proposed for the school year 2021-2022 a new format for these student projects. For this new occurrence of the course, all the projects have been proposed directly by the pedagogical team. This approach, compared to the previous one, has many advantages: similar level of difficulty for all the proposed subjects, content that perfectly frame the pedagogical content of the course, possibility to include questions related to all the three parts of the module, including part III³, etc. The originality of our approach has been the development of a database using the Airtable online tool (Porter, 2016). This tool offers a user-friendly interface, visualization facilities, as well as modularity and scalability features. Moreover, it also allows the co-working of all the contributors (possibly at the same time) to create the database in a virtual space. This newly created tool offers a dynamical panorama of subjects: it allows one to enter new questions, as well as the selection of a subset

of questions from the built database, for the projects that will be proposed in the next iterations of the course. New subjects can also be added each year, thus offering a large range of applications on system modeling. This database can be used for large-scale promotions of students with little efforts. In addition, it can be extended to other scientific/non-scientific domains.

The remaining of this paper is organized as follows. Section 2 focuses on the organizing procedures related to the group and project choices. Section 3 offers some technical details on the proposed tool, while an analysis is provided in Section 4. Concluding remarks are given in Section 5.

2. ORGANIZING PROCEDURES

A database of the subjects was developed by the teaching team using Airtable (Porter, 2016; Liu et al., 2012). More details on the proposed subjects are provided in Section 3.

First, the students chose their respective group and subject using the Moodle-based platform Edunao (Edunao, 2014). The teams are composed of 3 students. From the experience of the previous years, the pedagogical team noted that it is important to let the students choose their teammates and a subject in their field of interest. Thus, 300 groups named as $\text{Subject}_m\text{Group}_n$, with $m \in \{1, 2, \dots, 30\} \subset \mathbb{N}$ the number of the selected subject and $n \in \{A, B, \dots, J\}$ the label of the group associated to a given subject. Notice that in our case there are 30 different subjects (Fig. 1) and each subject can be chosen by 10 different groups. These two latter numbers can be seen as some tuning parameters that can be adjusted to manage the pedagogical objectives. However, their product is fixed to the total number of groups, 300 in our case. Increasing the number of subjects would lead to a larger diversity of topics to illustrate the versatility of the taught concepts. Conversely, increasing the number of groups for a given subject allows a fairer evaluation of the students' work (since they would be confronted in larger proportions with the same subject).

The project deliverables are composed of a short report and a simulator. Both L^AT_EX and MICROSOFT WORD templates (with typical outline and expected length for each section) were provided to the students in order to facilitate their work and improve their scientific report skills. Indeed, this report is one of the first that they encounter in their curriculum as first-year student, thus many of them do not yet master the standards of scientific reports. Regarding the simulation tools, the students mainly used PYTHON (Python Core Team, 2015) and MATLAB (MATLAB, 2018). It is worth being noted that Centrale-Supélec students already have, in general, a good level of programming in PYTHON before starting this project. This is essentially due to the training they received during the two years of higher education "Classes préparatoire" before joining CentraleSupélec and to their first programming courses. They are generally much less familiar with MATLAB. However, all the students of the course *Model Representations and Analysis* are requested to attend the "MATLAB onramp" online training (Matlab (2014)) before the first tutorial of this module. Notice that MATLAB is used for the numerical illustration of all the tutorials of the course. This helps students to better manipulate the MATLAB/SIMULINK environments, which is an important

² During the first occurrence of the module, the students were randomly distributed in teams of three members. After taking into account the students' feedback, they were allowed to choose their classmates to form teams of 3 students. This freedom given to the students in constituting the working groups has resulted in a significant increase of the quality of the students' work. It has also decreased the proportion of groups with problems of heterogeneity of workload share, often associated with the presence of the so-called 'free-riders' (student benefiting from the work of others in his/her group without contributing).

³ Note that in the previous version of the course, part III was excluded from the projects. This is because, due to time constraints, the students proposed the subjects well before the presentation of the topic of part III in class.

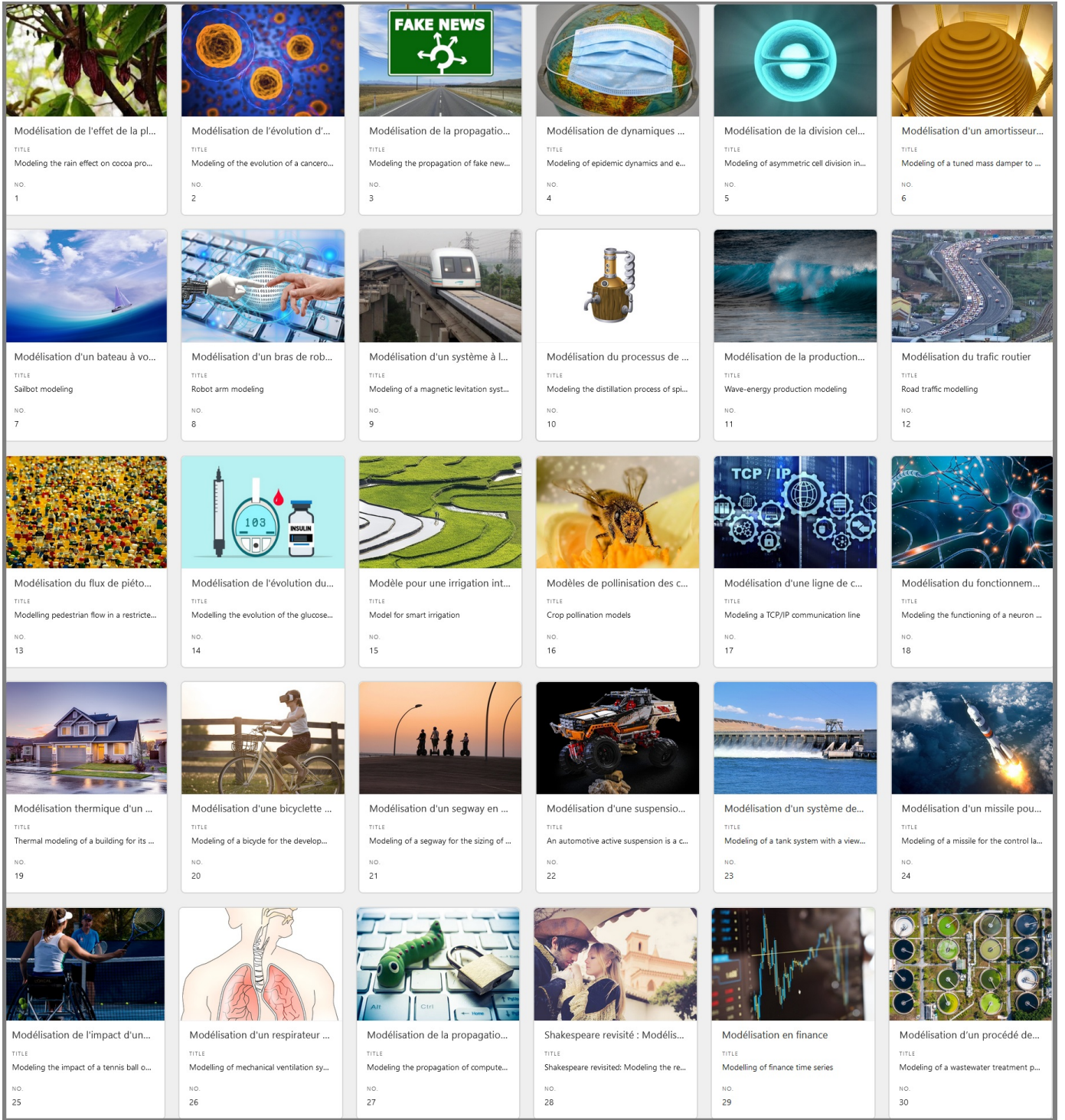


Fig. 1. Airtable *gallery* vizualisation example of the 30 projects

tool for system modeling and analysis. This is also in preparation of the course *Automatic control* which is part of the second year of training at CentraleSupélec.

After submitting the project deliverables, the students complete a “peer-reviewing” survey. More precisely, each group of students $\text{Subject}_m\text{Group}_n$ evaluates 3 different projects realised by other teams on a different subject. These three different projects are all on the same topic $i \neq m$, say $\text{Subject}_i\text{Group}_{n_1}$, $\text{Subject}_i\text{Group}_{n_2}$ and $\text{Subject}_i\text{Group}_{n_3}$ for some 2 by 2 distinct $n_1, n_2, n_3 \in$

$\{A, B, \dots, J\}$. The rationale behind this distribution are: (i) students assess a topic they have not themselves dealt with in order to be more impartial in their assessment and to discover an additional area of application of the modelling concepts studied, (ii) students assess three reports on the same topic in order to be able to provide a more robust assessment by comparing the deliverables against each other. Finally, the number of three reports seems an appropriate workload.

A Title	A N...	Select	Année	Picture	Context	Goal
Modeling the rain...	1	OK	2021-2022		Cocoa is an essenti...	The study will focu...
Modeling of the e...	2	OK	2021-2022		A cancer (or malign...	The objective of t...
Modeling the pro...	3	OK	2021-2022		Due to the rapid gr...	The objective of t...
Modeling of epid...	4	OK	2021-2022		The occurrence an...	The objective of t...
Modeling of asym...	5	OK	2021-2022		Hematopoietic ste...	The objective of t...
Modeling of a tun...	6	OK	2021-2022		A tuned mass dam...	The objective of t...
Sailbot modeling	7	OK	2021-2022		If the maneuvering ...	The aim is to stud...
Robot arm model...	8	OK	2021-2022		Recently, robotic ar...	The aim of this stu...
Modeling of a ma...	9	OK	2021-2022		Magnetic levitation...	The objective of t...
Modeling the disti...	10	OK	2021-2022		The alcohol produc...	The goal of this p...
Wave-energy pro...	11	OK	2021-2022		Renewable energie...	The goal of this p...
Road traffic model...	12	OK	2021-2022		Well-functioning ro...	Find the critical pa...
Modelling pedest...	13	OK	2021-2022		Understanding and...	Build a model to a...
Modelling the evo...	14	OK	2021-2022		Understanding the ...	Build a model for ...
Model for smart i...	15	OK	2021-2022		More than ever, ag...	To obtain a simpl...
Crop pollination ...	16	OK	2021-2022		The search for sust...	Obtain a simple m...
Modeling a TCP/L...	17	OK	2021-2022		The TCP protocol h...	The objective of t...
Modeling the func...	18	OK	2021-2022		Neurons are cells f...	The objective of t...
Thermal modeling...	19	OK	2021-2022		The building sector...	The objective of t...
Modeling of a bic...	20	OK	2021-2022		In northern Europe...	The objective of t...

Fig. 2. Example of *grid view* on Airtable

Notice that the pedagogical team did not find so far an appropriate tool for peer assessment by group. More precisely, the size of the student pool (300 groups of 3 students) implies the use of simple and systematic procedures to avoid as much as possible any hand-made corrections and assignments. For instance, the Edunao platform (at least the version available at CentraleSupélec) only allows a peer assessment option by student, not by group of students. Thus this peer assessment stage was implemented in Edunao via a survey, using a criteria grid. Indeed, several items have been added to the previous criteria grid proposed in Stoica Maniu et al. (2019a) in order to assess the state-of-the art, the analysis of the proposed continuous-state model (Part I) and discrete-event model (Part II), as well as the analysis of the uncertainty propagation/sensitivity analysis of the considered model (Part III).

A mailing procedure was then set up to send to each student individually a personalized message with the deliverables to evaluate in attachment. Better solutions need to be found and implemented in the future to efficiently handle the peer assessment process.

3. PROJECTS SETUP

There are 6 professors in charge of this module. Each professor proposed 5 different subjects for the projects, leading to a total of 30 subjects (recall that each subject is allocated to 10 groups of 3 students). Once the structure of the Airtable database was configured, each professor filled their subjects into the *grid view* as depicted in Fig. 2. Both French and English versions of the subjects were provided to the students. This was made possible by creating one *gallery view* per language and by selecting the appropriate fields.

An exhaustive set of questions was proposed for each of the three parts of the course. The proposed subjects for the English course track are available online at the link

provided in footnote⁴. This link contains the fields that the pedagogical team shares with the students. An additional field with a reference from the scientific literature (typically a scientific article under the form of a .pdf file), which can be used as a starting point by the students, is also displayed. The panorama of the proposed subjects can be visualized in Fig. 1 and the titles are recalled below:

- (1) Modeling the rain effect on cocoa production
- (2) Modeling of the evolution of a cancerous tumour
- (3) Modeling the propagation of fake news on social networks
- (4) Modeling of epidemic dynamics and epidemic containment strategies
- (5) Modeling of asymmetric cell division in hematopoietic stem cells
- (6) Modeling of a tuned mass damper to attenuate the oscillations of large infrastructures
- (7) Sailbot modeling
- (8) Robot arm modeling
- (9) Modeling of a magnetic levitation system applied to a magnetic levitation train
- (10) Modeling the distillation process of spirit drinks
- (11) Wave-energy production modeling
- (12) Road traffic modelling
- (13) Modelling pedestrian flow in a restricted area
- (14) Modelling the evolution of the glucose-insulin system
- (15) Model for smart irrigation
- (16) Crop pollination models
- (17) Modeling a TCP/IP communication line
- (18) Modeling the functioning of a neuron for the detection of synchronization phenomena between the neurons of a network
- (19) Thermal modeling of a building for its energy management
- (20) Modeling of a bicycle for the development of augmented reality algorithms
- (21) Modeling of a segway for the sizing of the motors
- (22) An automotive active suspension modeling
- (23) Modeling of a tank system with a view to optimizing the operation of a hydraulic valley
- (24) Modeling of a missile for the control law design
- (25) Modeling the impact of a tennis ball on a racket to help your classmate Emmanuelle Mörch winning at the Paris 2024 Paralympics
- (26) Modelling of mechanical ventilation systems for regulation of the expiratory cycle
- (27) Modeling the propagation of computer worms in Internet networks
- (28) Shakespeare revisited: Modeling the relationship of Romeo and Juliet, and more...
- (29) Modelling of finance time series
- (30) Modeling of a wastewater treatment process

One advantage of this database is its high modularity. This allows the teaching team to share only some parts of the database with the students and keep confidential some of the columns proposed in the grid view (see Fig. 2), e.g., which professor wrote the subject, questions kept in backup for the next years, etc.

Concerning the choice of the subjects given to the students, it can be noticed that a wide range of topics were

⁴ <https://airtable.com/shrt90k6YMFk6wkP4>

proposed: cocoa production models, fake news/epidemiology propagation models, wage energy production modeling, road traffic/pedestrian flow dynamics, sustainable agriculture models based on crop pollination, models used in finance, etc.

Another advantage of this tool is its scalability. It indeed allows to deal with a large number of subjects that can be efficiently reconfigured each year in order to provide new fields per subject (e.g. a new reference under the form of a .pdf file provided as a starting point for the project, new questions, etc.).

4. ANALYSIS

This section illustrates some insights of the mini-project implementation, mainly related to the group choice dynamics, the distribution of the discrete event models used during the projects, etc.

In the context of the realisation of these projects, the first action performed by the students was to choose their group and the associated subject. The time evolution of this group choice dynamics is depicted in Fig. 3: the measurements (blue stars) were made with a sampling period of one day during 8 consecutive days. Some of the students did not make their choice before the deadline, forcing the teaching team to randomly assign them after the deadline (red star). These students were grouped together in dedicated groups. It is possible to describe the dynamics of the group choice (and the associated subjects) by a first-order linear time-invariant model (see the blue curve in Fig. 3) given by the transfer function $900/(3s + 1)$ where s denotes the usual Laplace variable. One can remark that the time constant is approximately one third of the time allocated to the group and subject choice.

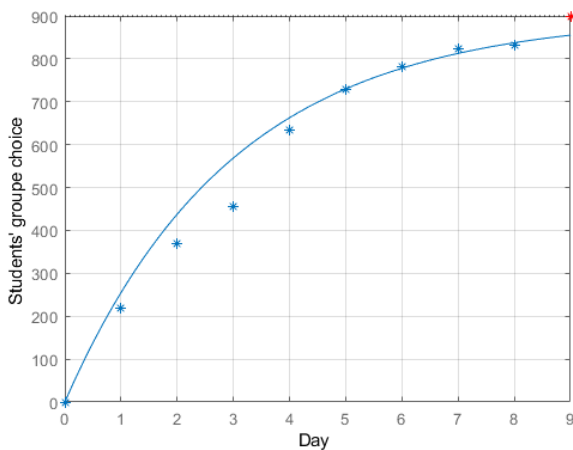


Fig. 3. Group choice dynamics (results are given in terms of student numbers, for groups of 3 students)

The students were expected to work autonomously on their project from mid-December to mid-January. A time slot dedicated to Q&A for the projects was scheduled in early January. Numerous students have attended this Q&A session with many relevant questions related to their specific project. This session has been very appreciated by the students. This also allowed the teaching team to have

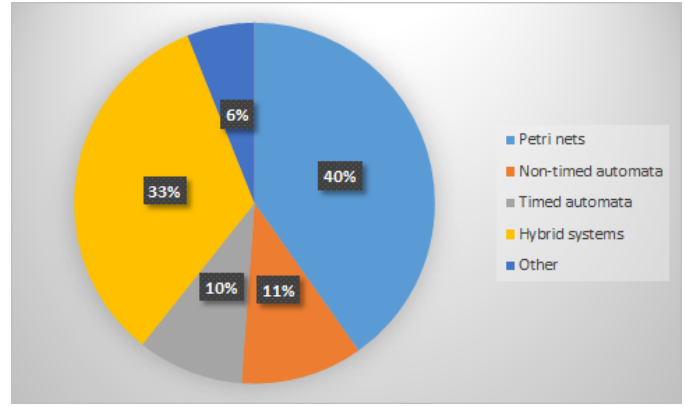


Fig. 4. Discrete event systems repartition

a first feedback on the progress of the projects and to help the students going into the right direction. The deadline for the projects was on mid-January with an expected workload of approximately 10h/student.

The first part of the module, related to continuous state models was successfully treated in most of the projects. This was expected because part I of the course spans over the 5 first lectures of the course (out of 10 lectures). Moreover, a significant part of the students already has some notions on this part of the course due to their two years of higher education in "Classes préparatoires".

In sharp contrast, the notions of discrete event systems (part II of the module) are new for almost all the students in this module. The students enjoy in general this part of the course and the associated tutorials. The statistical repartition of the methods used by the students in their project for modeling a discrete event system is reported in Fig. 3. We observe that Petri nets are the most used with 40%, followed by hybrid systems with 33%. It is worth being noted that some groups used concepts beyond the strict scope of the course (notions that were not taught in class). This includes cellular automata, Markov chains and stochastic automata.

The last part of the module (part III) dealing with uncertainty propagation and sensitivity analysis comes only a few days before the deadline for the project submission. Consequently, 43% of the students did not complete this part of the project. This is one of the elements the teaching team has to be careful about for the future iterations of the course. Mechanisms have to be found in order to allow the student to exercise themselves more efficiently on this part of the course.

Some statistics of the students' official feedback for this year module based on the responses of more than 60% of the students are provided below. The entire module was well appreciated by more than 90% of the students:

- course objectives (92%)
- clarity of the assessment process (94%)
- lectures/tutorials/projects distribution (87%)
- provided documentation resources (91%)
- consistency between the pedagogical activities (90%)
- adequate lecture pace (82%)
- structure and content of the module Edunao page (94%).

In addition, (70%) of the students agree that the Matlab onramp Matlab (2014) training allowed them to discover a new program language, (40%) of the students would have preferred a more advanced Matlab onramp training, (33%) of the students would have preferred to follow the Simulink onramp Matlab (2018) training also.

Concerning the projects, (68%) of the students were happy with the subjects proposed by the pedagogical team and not by the students, (79%) of the students were happy to have the possibility to choose their teammates for the projects, (41%) of the students appreciated to have the possibility to ask their questions on the projects during an official 90min time slot. In addition, (76%) of the students appreciated the report template (Word and L^AT_EX) provided by the pedagogical team. Only (31%) of the students appreciated the peer assessment process. The students were interested in working on a project in the following areas:

- (1) Healthcare (29%)
- (2) Social and techno-social networks (23%)
- (3) Transportation (32%)
- (4) Energy (32%)
- (5) Food (11%)
- (6) Sustainable development (24%)
- (7) Games, sport and music (39%)
- (8) Chemistry (10%)
- (9) Physics (34%)
- (10) Biology (16%)
- (11) Finance & economics (30%).

A short *a posteriori* analysis shows that in 2020-2021 approx. 20% of the subjects proposed by the students needed reformulation. In 2021-2022, when the subjects were proposed by the pedagogical team, only 5% of the subjects raised questions from the students. This was quantified by decreasing with 75% the number of exchanged e-mails with the pedagogical team on this topic.

5. CONCLUSION

This paper reported the implementation of a new Airtable-based database allowing to deal with a large number of engineering student projects. This data-base offers a user-friendly design that can be embedded in web pages and Moodle-based pedagogical platforms. It may be deployed for increasing the visibility of *System Modeling* and *System Control* at a large scale, within the student, industrial and research communities. The modular architecture allows providing perennial and reconfigurable subjects while decreasing the workload of the teaching team. This database can be easily generalized to other scientific/non-scientific fields.

To prevent a database that could circulate among the students in the near future, the existing subjects will be reconfigured (by modifying different questions/parts of the existing subjects) and new subjects will be added to the database.

Future work will mainly address the possibility to share the developed Airtable-based projects within the Control Systems community, providing co-working facilities at the international level and leading to a sustainable and helpful common database.

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