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FermProc: A Pedagogical Simulation Tool for Fermentations

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INTRODUCTION

Simulators are valuable educational tools enabling students to gain more theoretical knowledge and conceptual understanding [1], [2] due to the manipulation of the models allowing an intuitive learning based on action and offering the student a feeling of control and enhancing explorations. However, it is common that the simulators used in engineering education are conceived for simulating rigorous designs lacking of a thoughtful learning design. Therefore, they are not primarily designed for education and are not well-equipped with tools and frameworks that can enhance the learning process. More specifically, commercial virtual laboratories and/or simulators work as black boxes so their mathematical models are not displayed and it is not possible to recognize the assumptions made [3], [4].

Furthermore, another significant issue faced by the traditional lecture and textbooks system is to find a way of making complex theoretical knowledge more approachable and to create a long-lasting learning experience that can develop into more in-depth learning. Moreover, learning has to be enjoyable. One way to tackle these objectives is to incorporate game-based elements into learning design [5]. Individual student engagement is one of the challenges of the current education system since, in a majority of cases, the learning was designed without considering the new habits and interests of the students [6]. In this context, the use of games or the introduction of game elements inside a computer-aided pedagogical platform may create a new learning process that corresponds better with the new needs [7].

In this work, an educational computer-aided tool for teaching a specific case study based on a target group of students is developed. This simulator is the result from the application a previously developed methodology in which it integrates the description process as well as the learning design and the introduction of game elements [8].Therefore, the simulator, *FermProc*, can be further expanded to other processes and learning designs. Finally, it is a brief overview of the current state of FermProc and its learning design is presented.

1 REVIEW OF EXISTING SIMULATORS IN FERMENTATION

One of the disciplines that benefit from virtual laboratories is biochemical engineering. In the case of fermentation processes, they may have volumes up to 2500 m^3 in a real-world production facility [9]. Therefore, a physical student laboratory of this production volume is not feasible. Some of the available platforms to simulate fermentation processes are summarized in Table 1.

Table 1. Brief overview of some simulators used in the teaching of fermentation.

Software	Description	Disadvantages	Literature
Labster	Fully interactive advanced lab simulations	The implemented models cannot be visualized and it has a limited pedagogical range	[10]
SmiSci Pro//II	Software for the optimization of the plant performance implemented based on the calculation of rigorous heat and material balances. It is a development simulator.	The software works, as a black box with a predefined set of kinetic expressions and its educational value is limited to the overall process developed.	[11]
Aspen Hysys v 7.3	Dynamic process (of development) simulation software.	The software doesn't have implemented any bioconversion but only 5 possible kinetic expressions, limiting the accuracy of the model, as well as it educational value.	[12]
SuperPro Designer	Software for the modeling, evaluation, and optimization of integrated processes. It is a development simulator.	The fermentation unit has predefined models and cannot be modified and therefore, it has limitations for the simulation of a fermentation process.	[13]
PLVPQ	A web- server simulator for chemical and biological processes.	Although it can have different possible configurations for the fermenter, it doesn't allow the display of its model or its modification.	[14]

AQUASIM	Software for simulation and data analysis of aquatic systems	It is the most flexible software concerning model definition, as it has to be specified by the users, and therefore the user requires previous knowledge of kinetic models.	[15]

However, as listed in Table 1, the most common educational tools for teaching fermentation lack learning design and require a previous knowledge of the systems; which result in a loss in the pedagogical value of the simulator. Moreover, the literature search shows a lack of fermentation simulators that allow the visualization and modification of kinetic models combined with a thoughtful learning design.

2 USER NEED IDENTIFICATION

The first case study, demonstrated through implementing a previously developed computer-aided modeling framework [8], was chosen based on the requirements for the 3rd Semester subject of Kinetics and Modeling of Bioprocess in the bachelor of Sustainable Biotechnology in Aalborg University in Copenhagen, Denmark [16]. Therefore, the learning goal involves the acquisition of knowledge about all the steps for the description of the aerobic cultivation of *Saccharomyces cerevisiae* in glucose and its by-product ethanol in a stirred batch tank reactor. Furthermore, in order to establish the need related to this process, a survey was done with 10 students participating in the mentioned subject.

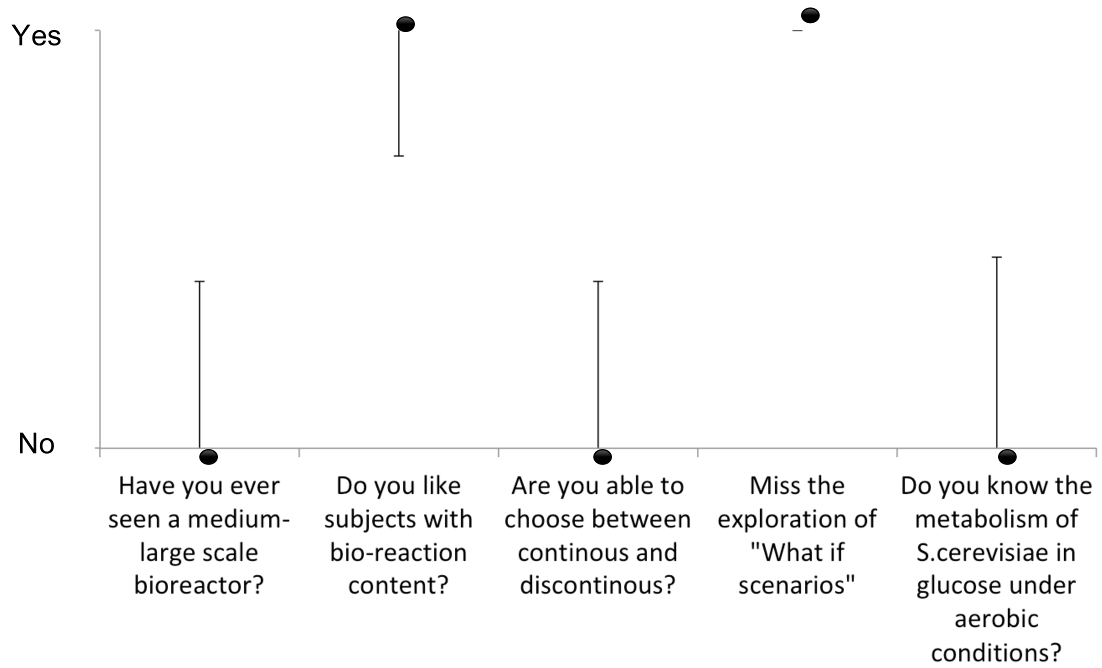

Fig 1. Survey for the need identification for the used of a simulator for the learning of the aerobic cultivation of *Saccharomyces cerevisiae* in glucose and its by-product ethanol in a stirred batch tank reactor.

As seen in *Fig. 1*, it was found that 80% of students have never seen a medium-large bioreactor, whereas the same percentage of participants were interested in the bioconversion process. On the other hand, 80% of the participants were lacking confidence in the choice of important process configurations, such as continuous versus batch operation. Finally, the need was identified as 100% of participants missed the possibility of exploring fictional and non-fictional scenarios, while 80% recognized that they did not have any previous knowledge of the kinetic model for *Saccharomyces cerevisiae.*

3 FermProc

FermProc is the resulting computational tool from the implementation of an existing computer-aided modeling framework integrating game-based learning with a specific learning design.

3.1.1 FermProc challenges

Due to its pedagogical aim and its conceptual design, *FermProc* must be trusted by the student, user-friendly, able to provide the user with an enjoyable learning experience, and with an easy architecture for the addition of new models or modifications of the existing ones. The main challenges for this platform are:

- To provide an organized and free-flowing learning experience. To solve this problem, clear directions are supplied in the platform.
- It must allow and encourage the modification of the model. To do so, the parameters that can be modified are displayed and the kinetic tendency and learning hints are also included to facilitate the experiential learning.
- Feedback must be intrinsic and variable. This is an important element for the implementation of the learning design and gamification. Using one question as an example:

  When you choose a production organism, the best choice is:

  1. An organism, which can only function under aerobic conditions.
  2. An organism, which can only function under anaerobic conditions.
  3. <u>An organism, which can only function under aerobic conditions and anaerobic conditions.</u>

  Although this question is not a challenge for the target group users, it promotes reflections about the different considerations that need to be taken into account and intrinsic feedback is provided to take the knowledge a step ahead.

Feedback: Aerobic growth can be convenient for biomass production (previous to product formation), because the growth rate is generally much higher. Meanwhile anaerobic growth can give higher yields and lower process costs due to the absence of oxygen required in the process. Therefore it can be useful to have an organism that can grow both aerobically and anaerobically. For example, in case you want to perform fermentation in which you separate a growth phase (batch, aerobic) and a production phase (feed phase, anaerobically). Can you think of an example? Do you know how beer is produced? Maybe ask the person next to you…

This learning follows a constructive learning design. Also, the last sentence invites to a collaborative learning. However, it has not been integrated into the platform as a chat box or other communication system at the current stage of the platform. On the contrary, some of the questions are still using an instructions approach. The corresponding extrinsic feedback can be seen in *Fig 2*:

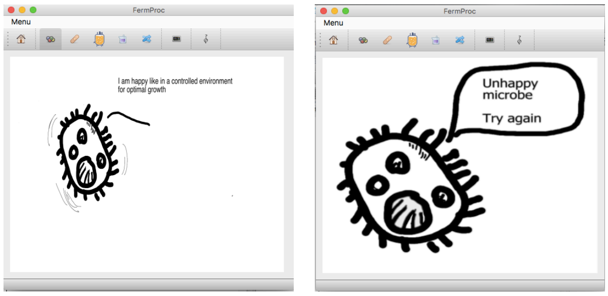

Fig. 2. On the left, the positive extrinsic feedback in which a microorganisms is saying "*I am happy like in a controlled environment for optimal growth"* and on the right, negative extrinsic feedback.

It is important to highlight that the platform has been designed with a constructive learning design aimed and therefore this feedback will be modified into an intrinsic feedback.

3.1.2 Decision making, introduction of game elements and creation of "What if" scenarios

FermProc aims to provide tools for decision-making and critical thinking to the students. In order to do so, it is designed a series of choices with an interactive respond from the software. This can be seen in *Fig.3* and *4.*

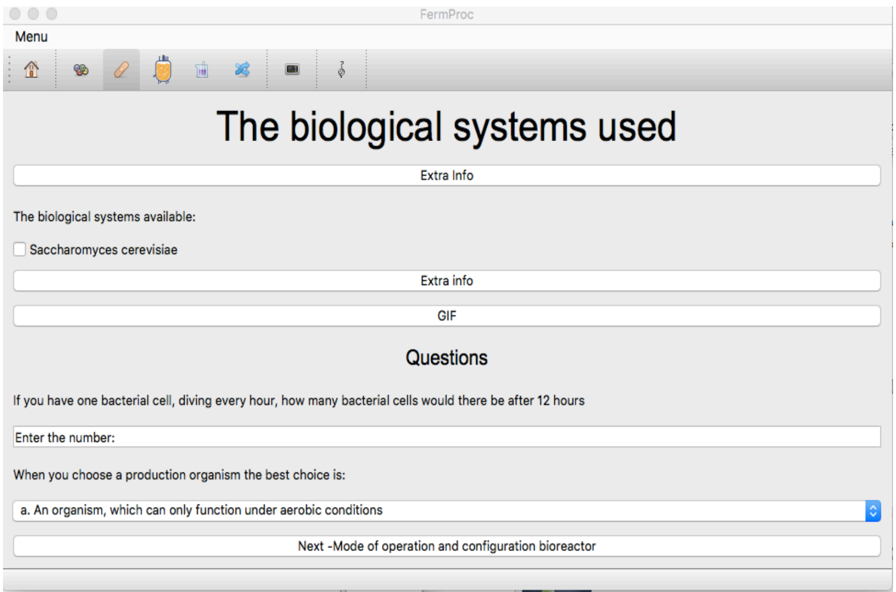

Fig 3. Capture of the screen for the biological system used. It integrated the choice of the biological system to simulate, its information, a gif and, independently of the biological system, a series of questions.

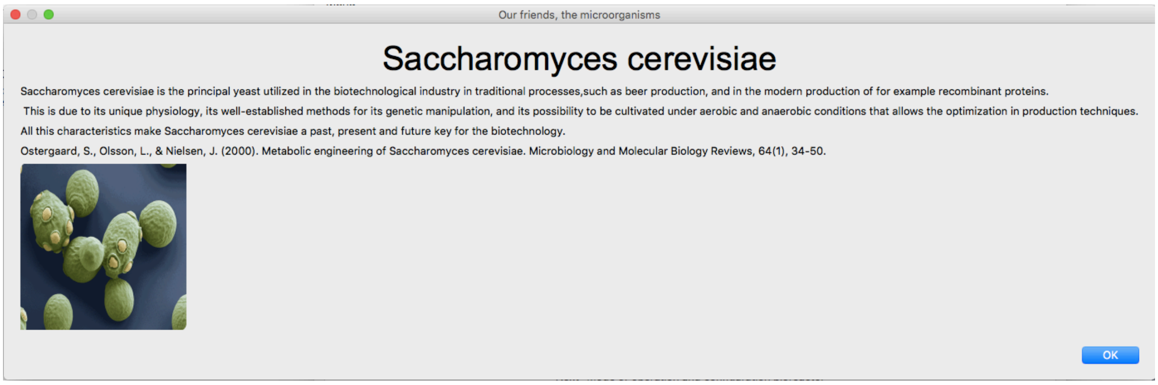

Fig 4. Learning hint about *Saccharomyes cerevisiae.* The information can be found in [17]

Furthermore, apart of questionnaire with score system and rules, it is implemented in the current state of the project a mini-game in *Fig 5.*

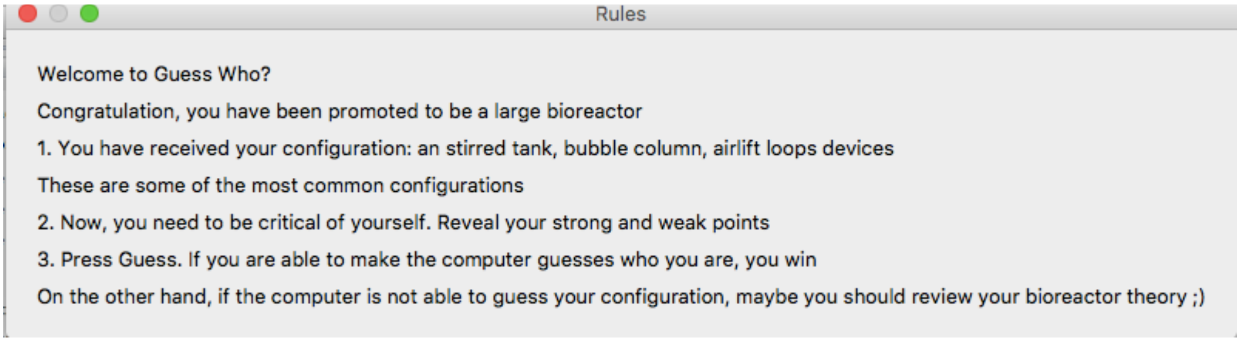

Fig 5. Capture of the rules of the Guess Who? mini-game

Finally, once a student has provided all the information required to describe fermentation conditions, the student can briefly see and modify the mathematical model as it can be seen in *Fig 6.* And *7.*

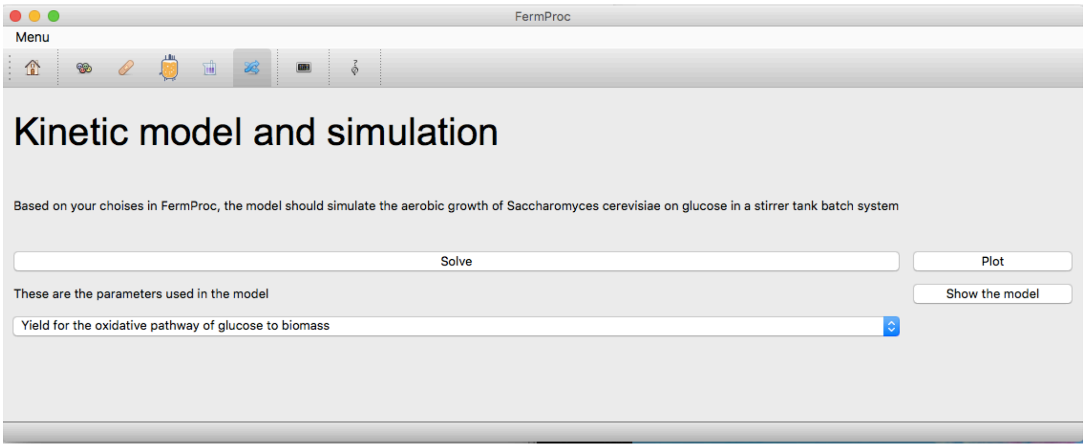

Fig 6. Capture of the screen of "Kinetic model and simulation". In this screen, students will see the mathematical model if they press show the model, or will plot it if they press plot or they can see the different parameters of the model, select them and modify them.

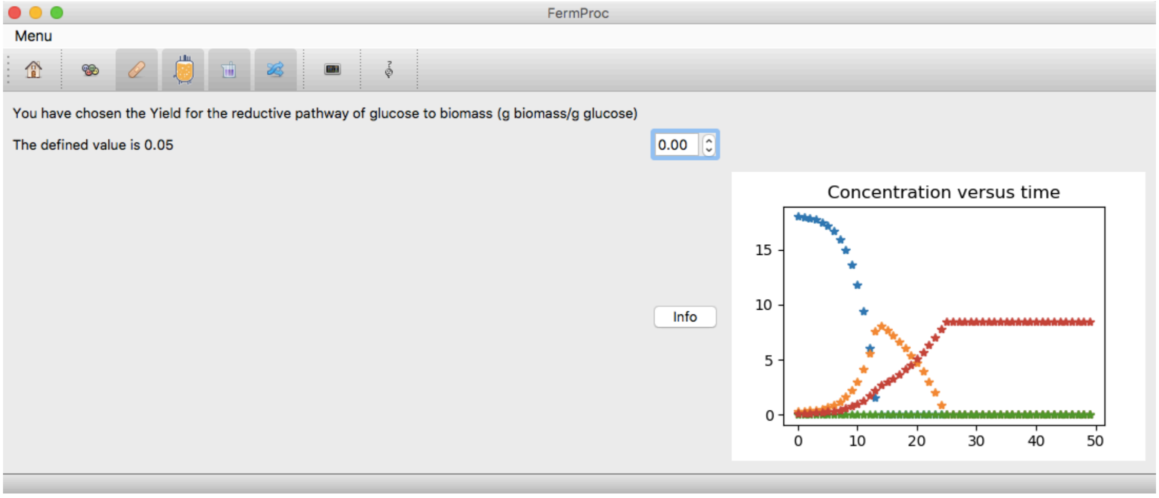

Fig 7. First screen for the modification of the kinetic model. In this example the yield for the reductive pathway of glucose to biomass is chosen. The color code is blue for the concentration of glucose, orange for the concentration of ethanol and red for the concentration of biomass. Y-axis corresponds to the concentration (g/L) while the X-axis is the time (h).

Furthermore, the platform integrates educational videos that so far provide information for the dissembling of a fermenter and the pieces that form it.

Although it was not possible to test the resulting software with a group of students, previous works have shown benefits in the use of simulators with game elements as a complement for the traditional lectures like in mechanical engineering [18] and computer science [19]. It is important to highlight that *FermProc* is still in development and will undergo several changes based on the feedback from future user experiences.

4 CONCLUSIONS AND FUTURE WORK

Based on a literature research and a student need survey, a computer-aided tool with the integration of game elements and a thoughtful learning design was developed using a framework for the development of pedagogical simulators. Therefore, this tool presents an interactive information flow for the display of learning hints, questionnaires, and the modification the model. Furthermore, *FermProc* provides predefined intrinsic feedback and the possibility to try different kinetic scenarios, along with hints and theory behind every choice of the user, multimedia content, and a mini-game.

5 SUMMARY AND ACKNOWLEDGMENTS

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