Informal Ways to Educate about Formal Modeling and Simulation with Petri Nets

Lara Zakfeld, Stefan Haag and Carlo Simon

Hochschule Worms
Erenburgerstr. 19, 67549 Worms, Germany
Email: {zakfeld, haag, simon}@hs-worms.de

***Abstract*—Linking current research and advanced teaching is one pillar of higher education. Students need to be prepared for finding novel solutions for challenges that arise from the digitalization of products, services, and production. To address these challenges, planing and forecasting play essential roles. These tasks can be handled by modeling to understand a real-world system, and simulating these models to gain insight into possible consequences of change. Formal modeling and simulation are highly complex activities that require experience and fitting tools. When lecturers integrate such exciting and cutting-edge topics, classical head-on teaching is not enough. Instead, they need inspirational approaches and reliable tools to provide learners with an easy-to-grasp, direct, and engaging introduction into modeling and simulation. This paper presents different approaches to engage students in this task. Case studies illustrate theoretical and practical business knowledge. The firing rule of Petri nets can be explained with mazes. Learners experience the implications of digitalization in production with real models of assembly lines controlled by Petri nets. Students are enabled to act as consultants who develop simulation models that incorporate planing and forecasting. Such extensive user interaction requires elaborated tool support but offers the possibility to intertwine teaching, theoretical learning, practical application, and current research.**

***Keywords*—Modeling; Simulation; Interactive Education; Digital Twins; Petri Nets.**

I. Introduction

In recent years, there has been a shift away from fact-based teaching to more involving methods such as problem-based and research-oriented learning. As a result, new concepts like inverted classrooms, blended learning or case studies become more commonly used by lecturers. These varied and active learning experiences encourage student engagement and secure a lasting learning success.

This ongoing process alters the roles of lecturers and students alike. While teachers shift more into the role of mentors and trainers, learners become more responsible to actively acquire new knowledge. Thus, the connection of current research, teaching strategies, and student motivation needs to be considered [1].

Experience shows that high engagement leads to more attendance in lectures and a striking correlation between course attendance and exam results of competency tests can be observed. Consequently, the acquisition of professional competencies is significantly promoted [2]. In a survey of 463 teachers on inverted classrooms, 67 % reported that the grade point average had improved and 99 % confirmed that the concept would be maintained [3].

Interactive engagement can induce such positive effects. A contemporary method is gamification. This catchphrase refers to the idea of using game design elements in a non-game context to motivate and increase user activity and retention. Gamification is an approach already used in areas as diverse as finance and education [4]. Yet, it raises the question about how other game-based or interactive techniques can improve students' learning experience.

The *Group of Applied Process Simulation* (*GAPS*) at Worms University of Applied Sciences pursues the goal to integrate active research in modeling and simulation with Petri nets with interactive teaching. The technological backbone is the *Process-Simulation.Center* (*P-S.C*), a Petri net WebApp which is used as a virtual laboratory. It incorporates features of integrated management systems based on Petri nets, organization charts, and process maps and is the hub for gamification, blended and interactive learning, and case studies.

- Semester-long case studies evolve student's competencies regarding business processes and their simulation in an organized and coherent fashion.
- Petri net mazes teach operational rules in a game setting: the faster a maze is solved, the more points are awarded.
- Real world assembly lines in toy size improve the understanding on how production processes can be modeled, predicted, and controlled with Petri nets.
- Consulting projects deliver more insights into the complex challenges that the real world poses.

This approach goes beyond the work of [5] and [6], which explain how to teach basic Petri net modeling techniques. However, they do not include teaching a case study nor enable teachers and learners to cooperate within the tool. Hence, it provides practical experiences and suggestions to lectures in the field of simulation and develop existing approaches further.

The following Section II classifies the approaches presented in this contribution. Section III explains some basics on Petri nets while Section IV provides information about the *P-S.C*. Section V shows how to connect business process management with simulation and modeling by using case studies. Then, Section VI describes how gamification can be used for teaching Petri net fundamentals. Practical modeling aspects in an engaging live setting are outlined in Section VII. Afterwards, Section VIII describes the use of current research as an example application. A conclusion and future work is detailed in Section IX.

II. Learning Pyramid

How can lecturers ensure that the approaches they choose and practice will achieve the desired outcome? How to activate a learning group? These and comparable questions arise for lecturers when they want to improve their teaching, since different approaches enhance competencies at different strengths.

The learning pyramid as depicted in Figure 1 classifies different approaches and their retention rates. The figures on the left show the different learning coefficients (average retention rate) based on the teaching methods (shown directly in the pyramid). The most active and participative methods have the highest learning coefficients [7].

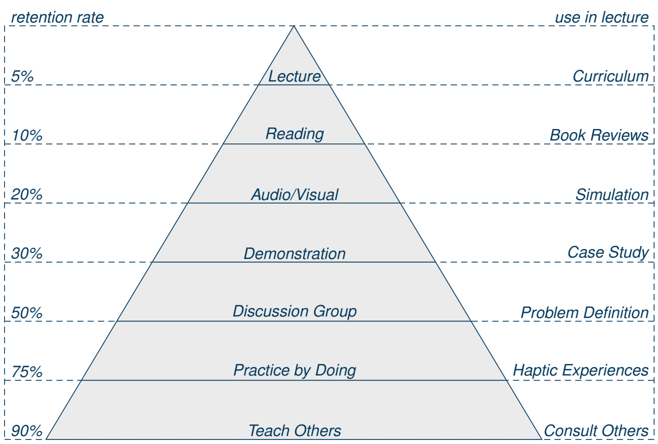

Fig. 1. Learning Pyramid.

The figure's right side shows the methods with which the specific retention is aspired in the presented courses. A head-on lecture or an assignment to write a book review have low retention rates. The use of an integrated case study in combination with a problem-based introduction to the respective unit increases the retention rate considerably. Haptic experiences with suitable tools have exciting effects, as discussed in the next sections. The weekly presentation of results and, thus, teaching by students leads to the highest retention rate.

III. Enabler Petri Nets

As a formal modeling language, Petri nets can be used to model and simulate the behavior of dynamic systems. A Petri net consists of two node-sets: places are marked with information and transitions can operate on this information. The allocation of information on places indicates the systems' state. Information flow is established by alternately linking places and transitions with directed arcs [8].

Originally, in Place/Transition (P/T) nets, information is depicted as anonymous tokens. In high-level nets, like Predicate/Transition (Pr/T) nets, the marking may contain arbitrary data and can be regarded akin to data sets in a database.

The so-called firing rule formalizes state changes: a transition is enabled iff its pre-set places carry sufficient information and its post-set can receive information produced when the transition fires. When an enabled transition fires, the information flow is established [8].

The expressiveness of Petri nets can further be enhanced by time concepts which is relevant for modeling real world processes or real world technical systems [9].

However, the dilemma of explanations like in this section, textbooks, or papers on Petri nets is that they cannot convey the actual dynamics of an operating Petri net. A dedicated tool is needed to experience this and to profit from their capabilities.

IV. The Process-Simulation.Center Our Simulation Lab

The *P-S.C* is an integrated management system that allows for modeling the structural and process organization of corporate entities. It uses P/T and Pr/T nets to establish simulatable models and integrates swimlanes, organizational charts and process maps [10]. Real-world data can be incorporated and used for simulation, planing and forecasting purposes [11]. The development process combines Design Science Research Guidelines and Evolutionary Prototyping [12][13].

Figure 2 depicts the process of academic user registration inside the tool. When a new user registers with the system, they receive the general role of guest. If the corresponding mail address is connected to an education tenant, they may adopt a lecturer or a student role. A lecturer then may define groups and assign tasks to the student groups.

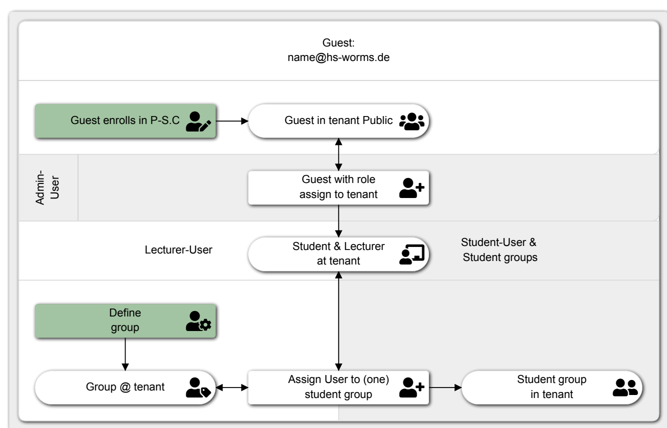

Fig. 2. The Laboratory in Action. (P-S.C export)

As a WebApp, the *P-S.C* can be used on personal computers or mobile devices. The *P-S.C Cloud* is set up to serve different tenants (and clients) simultaneously. Users in multitenancy system can work without getting insight into other tenant's settings, users, or data, just as if the environment was exclusively available to them (as stipulated by [14]).

Additionally, the *P-S.C* and a dedicated interface can be executed on a Raspberry Pi™, a simple but capable single-board computer. External sensors and actuators then can be connected to its input and output pins. Input and output data is put on a Petri net model's places, which allows for computation and further processing. Thus, the *P-S.C* is able to control real-world devices [15].

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V. Case Study Based Semester Schedule

University teaching aims to train young adults in the best possible way for the challenges they face after graduation. To put this to practice, a case study was developed in which students are guided by the concept of problem-based or research-oriented learning. Initial approaches have already been presented [15]. Through the continuous development of the *P-S.C* as well as the case study ¨bureau4us GmbH¨, new opportunities open up.

The pivotal point here is the *P-S.C* as presented in Section IV. Through a dedicated tenant for the respective course, a learning group of 2-3 students can also exchange and work with each other in the virtual lab. During a semester, students model and simulate processes of the fictitious company ¨bureau4us GmbH¨.

Furthermore, to increase the identification between the case study and the learners, the protagonist of the case study, Tina Nett, is also a student in the respective semester. Tina works with some fellow students as an intern in the fictitious company and is assigned to the various departments. The learning group acts as a consulting team to Tina and presents the developed solution to the actual auditorium in the following week. The fictitious student group is pictured in Figure 3.

Fig. 3. A Fictitious Student Working Group.
(photo by Jason Goodman on Unsplash)

This schedules a single lecture and exercise unit as follows:

1) A unit starts with a presentation of the current problem at bureau4us GmbH given by the fictitious protagonists.
2) The lecturer teaches the named topic and delivers the current unit.
3) Then, the problem is transformed into a direct work assignment for the students.
4) Students are provided with workspaces such as free models in the *P-S.C*. Small student learning groups operate in their workspace.
5) Feedback is given within the tool as an integral part of an approval workflow.
6) The students present their results in the auditorium using the *P-S.C*.

This loop takes place iteratively from week to week. Thus, students are further immersed in the real problems of a fictitious company. The case study and the presented workflow have been successfully used for three semesters in Bachelor and Master courses. This setting motivates lecturers and students to continuously develop the case study further, for example concerning the following topics:

- A website of the bureau4us GmbH for deeper immersion.
- An interactive purchase order interface which directly connects bureaus4us and simulations on its data.
- Strategically anchor the individual process goals and, thus, further develop the *P-S.C* as an integrated management system.

Through such active and interactive teaching, both sides, learners and lecturers, can continuously develop in their skills. The knowledge gained is also incorporated into the accompanying industrial projects, one of which serves as an application example and is described in Section VIII.

VI. Petri Net Mazes

A maze game as depicted in Figure 4 allows for an easy introduction to the basic rules of Petri nets. As the *P-S.C* also runs on tablets, users may tap on transitions to make them fire. Enabled transitions are colored dark-green while places with tokens to be collected are colored light-green. The objective is to clear the net in the shortest time possible while leaving no tokens inside. A timer starts running as soon as the transition in the upper left fires. It stops when the last transition in the lower right fires. Remaining tokens lead to penalties.

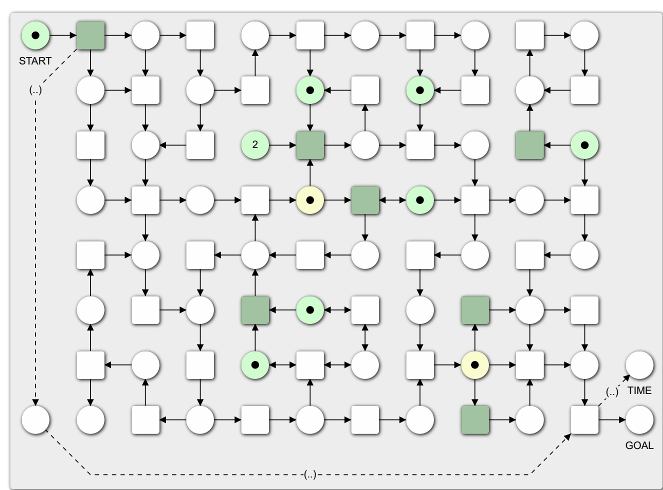

Fig. 4. A medium-sized Maze. (P-S.C export)

Both the mazes' playability on tablets and the race for high scores strongly activate users and, thus, impart knowledge on how Petri nets work. The mazes have been used successfully at several occasions from eight-year-old pupils' STEM courses via lectures for students in their twenties to presentations for seasoned professionals.

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VII. Digital Twins in Education

The Industrial Internet of Things (IIoT) and digitalization are prominent topics in public discourse. To ready students for the challenges these and other technological developments pose, the connection of real world applications and business processes has to be conveyed. To this end, cyber-physical systems seem beneficial.

Such systems consist of at least two components: A real-world one, and a digital one. These components are considered twins in the sense that the digital and real twin behave correspondingly. To be more precise, the digital twin, when executed with real data, should calculate the same state that the real twin reaches while providing this data [16].

Figure 5 shows a complete setup suitable for teaching the concepts of digital twins, IIoT, and digitalization. A fischertechnik™ assembly line model features several different sensors and actuators. The sensors are connected to the input pins of a Raspberry Pi™. The output pins in turn are connected to the actuators of the model. This setup corresponds to wiring connections that are used in real-world industrial applications.

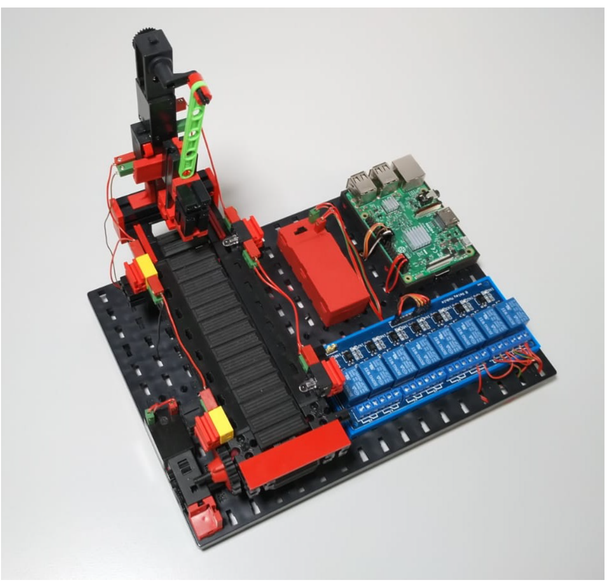

Fig. 5. Raspberry Pi™ (upper right) Connected to a fischertechnik™ Model (left) and a Mutli-Channel Relay (lower right). (photo by Stefan Haag)

The digital twin is implemented as a Petri net model in the *P-S.C*, as shown in Figure 6. The tool is installed on a Raspberry Pi™ and runs in a browser. An interface program that is also installed on the Raspberry Pi™ routes incoming signals to the Petri net model. These signals are used on special input places where they act as tokens and, thus, allow the Petri net to reach the next system state. Correspondingly, special output places are used to control the fischertechnik™ model: When a token is placed, the interface translates the token's data into control commands for the actuators. As is the case in industrial applications, the control signals do not directly influence the actuators, but use relays for load control.

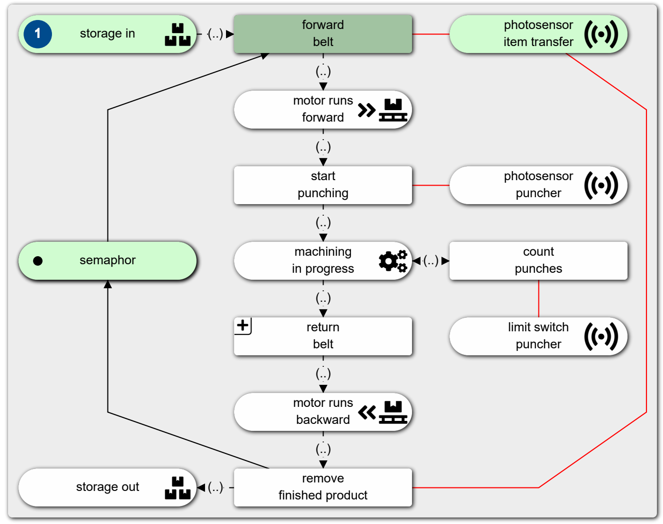

Fig. 6. Control Petri Net of the Digital Twin.

By interweaving imported data, business logic and process models with input and output places, this configuration acts as real and digital twin. The setup lets learners experience the concept of digitalization in an industrial setting first-hand [15].

VIII. Industry

The ways to educate students about formal modeling and simulation presented so far are the first steps. When lecturers include real examples with real challenges, the previously described path as well as the teaching content is rounded off.

The focus of a current knowledge transfer project with an industrial partner is to simulate a new warehouse, which is currently under construction. The warehouse is dedicated for dangerous chemical and pharmaceutical substances and offers space for more than 22,000 palettes. A simulation must be flexible enough to compare different delivery strategies in front and within the warehouse.

GAPS faces the challenge to simulate these processes in a user-friendly way to give the industry partner a feeling for the future operational processes on site. The simulation is part of the resource planning of manpower and investments into forklifts for the warehouse.

Figure 7 shows process description and model of the loading area in the yard. The sub-process involves coordinating trucks booked into the system at the yard, allocating the correct loading ramp, loading the goods provided and measuring the required truck throughput time. The goal of this process is to establish a sound foundation for operations. This is also shown in the process description in the left side area.

An important finding was to evaluate the exported data from the simulation in a visually appealing way as shown in Figure 8. Trucks are depicted on their corresponding locations in the yard. When being loaded, the otherwise white trailer gets filled. A timer on the right side tracks time in the current working shift. Even non-modelers and non-simulationists can directly grasp the added value of the simulation.

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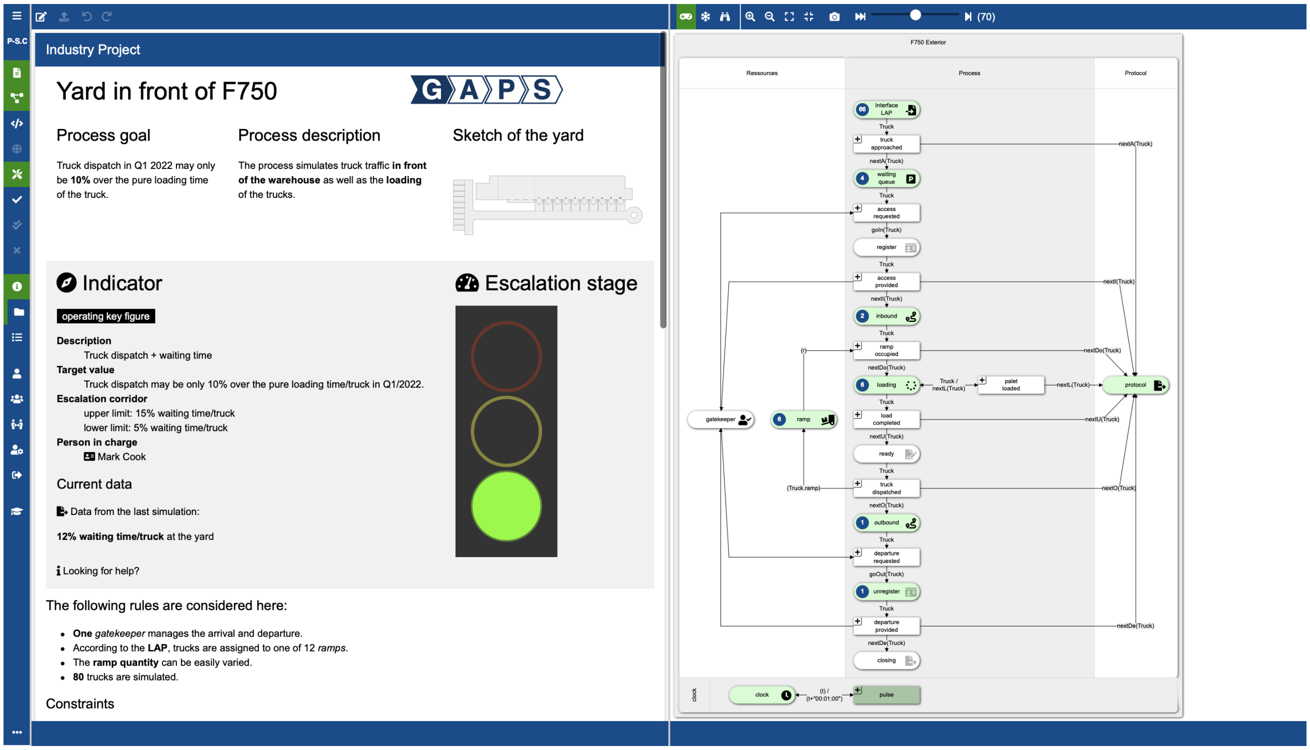

Fig. 7. One Model from an Industry Project. (P-S.C screenshot)

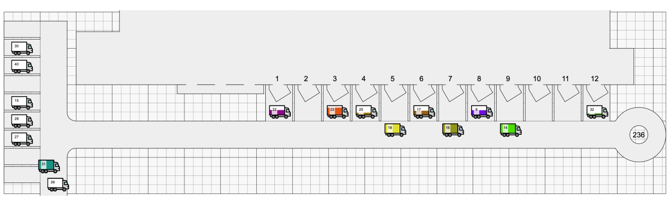

Fig. 8. Visualization of the Yard. (P-S.C screenshot)

This realization is also important for students. Appropriately holistic modeling and simulation tasks in the lecture train and develop these skills. They can transfer their observations from the case study described in Section V to a real world scenario.

The next step is to model the inside of the warehouse and, thus, simulate the goods provided as well. This will further enrich the experiences the students can gather.

IX. Conclusion

Modeling and simulation play crucial parts in practice. They enable a better understanding of complex systems as well as better planning and forecasting. However, as the complexity of the systems increases, so do the requirements for their modeling.

Thus, learners need a thorough and deep understanding of modeling techniques and how to handle simulations. To prepare students for this tasks, and to lower the entry barrier for new modelers, engaging and active learning methods are beneficial. In consequence, this necessitates proper tool support.

By using the *P-S.C*, five different examples for holistic teaching are presented:

1) Case studies let learners experience how modeling and simulation can help to deal with manifold business and technological challenges.
2) Mazes provide an interactive and fun activity to learn the basic Petri net rules and establish an entry point to model with formal methods.
3) Digital twins show the relevance to combine different fields of expertise in an accessible, haptic way. Also, they give first insights into the complex reality students face after graduation.
4) Real world examples further deepen the understanding of complex systems. They also provide guidance to handle these tasks in a structured manner.
5) Feedback is given immediately within the tool in form of an approval process.

The natural extension of this list is one possible research path for the future: Which other interactive methods to teach modeling and simulation can be introduced within the *P-S.C*? What functionality does the *P-S.C* have to provide for these methods?

In addition to methods that rely on the tool, what kinds of engaging, haptic methods can be employed? Further, can such methods be adopted to inspire enthusiasm in STEM courses?

Engaging teaching methods provide for motivated learners. In turn, motivated learners provide feedback on methods, technologies, and content. Thus, they improve education, research and practice alike. A worthwhile endeavor.

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