

# Understanding the Dynamics of Solar Energy Systems by Using Simulation Narratives

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## Abstract

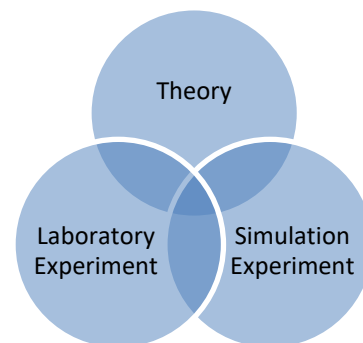
In this paper, we discuss the application of modern didactic approaches to solar energy education. We focus on the dynamics of decentralized energy systems and solar thermal applications. In order to bridge the gap between theory and practice, students are engaged in investigating solar systems in numerical analysis combined with hands-on laboratory exercises. Our learning material includes simulation software and state-of-the-art analysis tools for the post-processing of log data. We recognize similarities in the students' cognitive processes when they do simulations in one part of their practical work and hardware experiments in the other part. In both cases, the narrative nature of the processes are a key to a fundamental understanding of the underlying physics. For both the simulation approach as well as the hardware experiments, students train to explain the physical processes in words: Simulation software and hardware laboratory equipment are the "story worlds" and a specific simulation run or a measurement experiment is the "story" (Fuchs 2015). Consequently, students at the same time practice clearly phrasing their observations and extend their expertise in solar energy. They also train abilities like system modeling, parameter validation, and practical skills like the handling of large data amounts typically produced by logging devices. We conclude that a narrative approach helps to thoroughly understand the controller strategies in solar systems with all its consequences and at the same time enables solar engineers for successful communication with the various players.

*Keywords: Solar education, seamless learning, simulation narratives*

## 1. Introduction

The various types of usage of solar energy all require dealing with the stochastic nature of both solar energy production as well as consumption. Firstly, one needs to understand the key figures of solar energy systems, such as system efficiency and self-consumption. They are the basis for all financial considerations such as the calculation of payback time or net present value. Secondly, understanding the dynamics of such systems is important for the proper dimensioning of system components (thermal or electrical storage, selection of heat pump size, dimensioning of heat exchanger). Thirdly, optimizing modern energy systems, or in many cases simply meeting the future regulatory requirements, involves analyzing their dynamic behavior and working out scenarios. Consequently, teaching the dynamics of decentralized energy systems is relevant for both technical colleges and the training of specialists (see also Carberry, 2014). To some degree, this is also relevant for decision-makers in regulatory bodies, funding agencies and utility companies. In particular, we believe that the knowledge of the dynamics of thermal systems is of very high importance for the renewable energy engineers despite the fact that low cost photovoltaic systems dominate the renewable energy market today.

At Zurich University of Applied Sciences in the bachelor's degree Energy and Environmental Engineering, solar thermal systems are treated in the last year, employing a combination of a classroom teaching in classical lecture format with simulation exercises and hands-on experience in the laboratory. Simulations are done with Polysun (Vela Solaris, 2017). In this work, we compare the learning processes in simulation and laboratory experiments. Simulation experiments lately receive a lot of attention due to the digitalization of the engineering disciplines. We are convinced that a combination with hardware experiments remains important both in order to strengthen the technical understanding as well as in supporting the cognitive learning process.



**Fig. 1: Interplay between theory and experiment**

## 2. Seamless learning and the narrative approach in science education

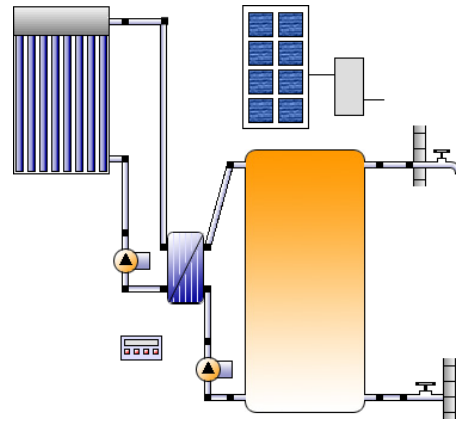
The paradigm of seamless learning is relevant for the teaching of engineering sciences because it recognizes the importance of paying attention to rifts, breaks, or divides, i.e., *seams*, in learning biographies and accounts for the impact of modern mobile devices and recent results in learning sciences relevant for the teaching process. We are concerned with such rifts in life-long learning where differences in form and level of technical education need to be bridged. In continuing education as well as universities of applied sciences, it is an advantage that students previously acquired practical knowledge as practitioners in an industrial work environment. It is equally an opportunity as a challenge to tie new theoretical contents to the individual experience of every student – in the seamless learning context, the relevant dimension is the learning across time and the “knowledge synthesys”, i.e. the conjunction of prior and new knowledge (Wong 2012). Likewise, the gap between theoretical and practical knowledge can be a major obstacle for graduates from technical universities to be successful in their first years as engineers in industry.

Furthermore, and with a specific relevance to dynamic energy systems, we recognize the three links between theory, the laboratory experiment and the simulation as major divides. As an example, it is a danger that theoretical knowledge cannot be transferred to the laboratory setting or that it students do not see the direct relation between a hardware experiment and the results of a computer simulation.

Being aware of the seams as described above, it can be one strategy to reduce the gap and design learning material in a way that the student clearly sees the similarities between the two worlds. As an example, the laboratory experiment and the simulation setup shown in Fig. 1 have a clear correspondence in topology. The student exercise is chosen to measure and simulate exactly the same period of time and the resulting curves can be directly compared.

Alternatively, we believe that the seamless learning paradigm helps to empower students to recognize and overcome divides that will inevitably exist in his professional career; the simulation–measurement divide being a classical challenge in the modern engineering world. Good learning results have been observed in a two-stage process where an initial phase was used to familiarize oneself with computer simulations and in a second phase students work out optimization problems with computer simulations and in hands-on laboratory exercises make measurements in the laboratory with an obvious rift between the two worlds.

The narrative approach as a common methodology bridges the gap: in both worlds, the students have to express their findings in words and describe the fundamental physical relationships. The time-domain nature of the dynamical processes give a good guidance in developing the “story” that needs to be told. Students identify the “actors” and describe how they influence what happens in the system. As an example, a controller has the temperature sensor at the solar collector  $\vartheta_c$  and at the bottom of the storage tank  $\vartheta_s$  as input parameters. Depending on a given set of rules, in this case if  $\vartheta_s < \vartheta_c$ , the controller activates the pump in the fluid starts to circulate in the solar loop. Students identify the mass transport, the energy transport and the flow of information as separate flow phenomena and gains a deeper understanding of physical principles.



**Fig. 2: Hardware exhibit (left) and computer simulation (right) representing very similar solar system designs, bridging the gap between laboratory experiment and virtual model.**

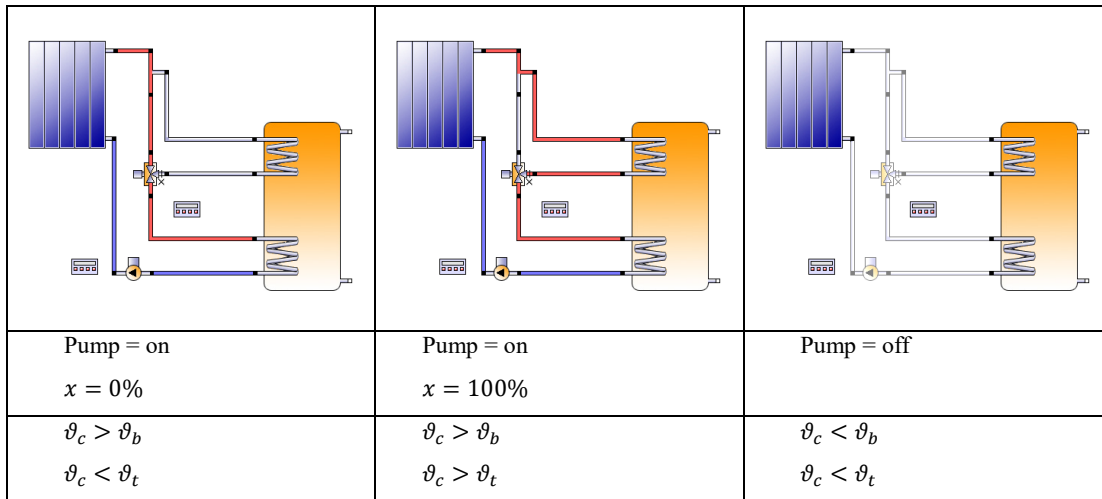
### 3. Practical work with experimental solar installation

The practical work experiences are fundamental in the engineering syllabus and is repeatedly trained during the course of studies. The solar thermal laboratory of the Institute of Energy Systems and Fluid Engineering at Zurich University of Applied Sciences is used during the practical exercises in the above mentioned course in solar thermal technologies. The goal is that students gain a general understanding of the behavior of different types of collectors under real conditions. Six types of collectors are installed in parallel on the roof of the machine laboratory building: one unglazed, one hybrid PVT collector, three glazed collectors, but with different reflection coating and absorber material, and one vacuum collector. The collectors are south facing with adjustable tilt angle (Fig. 4).

In the exercise, students use their own computers for the analysis of measurement results. In particular, they learn to handle large amounts of data and sharpen their engineering perception in interpreting simulation results and discussing the behavior and performance of the system under test and the different collectors.

The system can be operated in two different modes (Fig. 3):

- **Storage mode:** this mode help to get familiar with a solar system as normally is built. The collectors are connected to a stratified thermal water storage. Water is fed from the storage to external heat exchangers to simulated warm water users and space heating. The temperatures are monitored in the storage at different heights, so the students can have a picture of the temperature profile inside the storage and understand better the operation mode of the system (Fig. 3). More temperature sensors and flowmeters are installed along the circuit allowing a complete energy balance and the computation of the thermal losses in the circuit and in the storage itself (for example during the night).
- **Yield mode:** the scope is to determine the yield curves of the collector at different absorber temperatures. The temperature at collector inlet can be maintained constant at the required value by a cooling/heating system. That allows comparing the performances of different collectors under the same boundary conditions.



**Fig. 3: operation of the stratified thermal water storage.**  $\vartheta_c$ : collector temperature;  $\vartheta_t$ : top temperature of storage;  $\vartheta_b$ : bottom temperature of storage. Depending of the collector temperature, the three-way valve is controlled in a way that the collector fluid is fed to the bottom or upper part of the storage,  $x$  being the percentage of the flow as indicated in the schematic. In case the collector temperature is lower than the storage temperature, the circulation pump is turned off.

Another important aspect is the thermal inertia of the systems. The temperature sensors shown a time delay between a suddenly shading and the decrease in the collector yields as well as between temperature change at collector outlet and storage inlet. These aspects shall be analyzed carefully during the result validation in order to get correct results during transient conditions and to integrate these into the simulation tools.



**Fig. 4: Collector test field for lab experiments and student projects**



Fig. 5: Solar thermal Laboratory of the Institute of Energy Systems and Fluid Engineering (IEFE). Solar energy storage tank (blue), large reservoir as a reference for short term measurements (white)

#### 4. Results

Research on cognitive skills suggests that simulation narratives obtain a more central role in explaining how dynamic systems operate (Fuchs 2015). Students learn how to model the real world by creating a story world in their mind. Our approach trains them to talk in a colloquial but precise language about physical phenomena. They recognize the different flow quantities such as information, thermal energy, electrical energy, mass transport. The approach is particularly suitable in time domain simulations and in experiments with controllers that are equally have an inherent time sequence.

We expect the narrative embedding has a positive effect upon a widespread practice-theory divide, to lead to improvements in lifelong learning and in this way help alleviate the shortage of qualified technical specialists. In order to take into consideration breaks and rifts in individual learning biographies, we make use of the paradigm of seamless learning (Wong, 2015).

As scientists or engineers, we are not commonly acquainted with the idea of narrative aspects of our formal and practical work. Still, it has become apparent in fields as diverse as economics and physics that modeling and simulation are a form of narrative practice. Economists tell themselves stories about events from which they distill models (Morgan, 2001). In computational science, a simulation takes us through a series of events, a process that is rather unlike the results of a formal derivation based upon some laws of nature (Wise, 2011). Inspired by these observations, and by work in narratology that has pointed to the importance of the distinction between stories and story-worlds, we suggest that simulations resemble stories whereas models represent story-worlds (Fuchs, 2015). This suggests interesting avenues for education in fields that require computation. It points at simulations as sources of experience of the action of characters such as heat or electricity in natural and technical worlds in the same way that novels can be the origin of understanding of (human) characters acting in social and psychological worlds. Being exposed to such experience and learning to “retell” what is “seen” in these “stories” is expected to help create story-worlds, i.e., mental models, that allow a practitioner to better understand, and even criticize and extend, the models that underlie his or her simulations.

## 5. Conclusion and Outlook

We have followed the seamless learning paradigm in the design of teaching material starting with theory and subsequently deepening the knowledge both with use of simulation software and laboratory measurement. In a first step, exercises have been design in a simplifying way, reducing the gap between simulation and measurement. In a second step, the differences between a virtual system (numerical model) and a hardware experiment (laboratory measurement) have been emphasized, letting students develop their skills in switching between the two worlds.

Progress in a deep understanding of physical phenomena is observed during our courses. However, exam questions are not yet set up in a way that allows to measure the learning effect properly.

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