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Poster - Sim2Learn: Simulation of an Electron Microscope to facilitate Mental to Conceptual Model convergence

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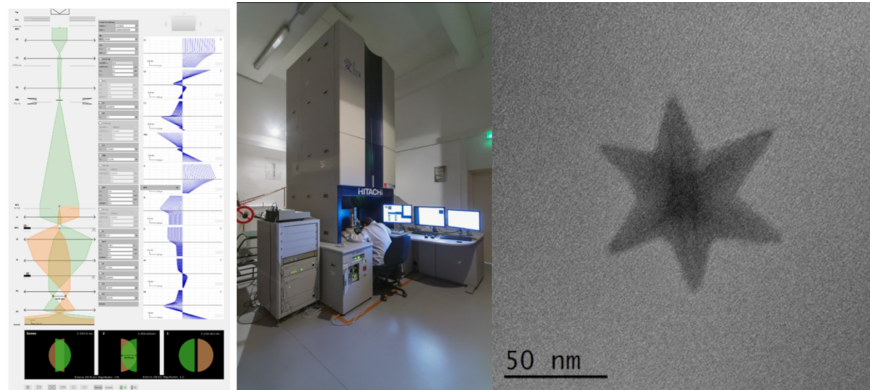


Figure 1: SimuTEM interface (left), I2TEM (Transmission Electron Microscope) at CEMES (middle) and an example of a TEM image of a FeCo nanostar

ABSTRACT

Scientific instruments such as electron microscopes allow rapid development in many fields of science but are difficult to fully exploit. Even for experienced users, their internal state (shape of the electron beam), represented in conceptual models, remains fairly inaccessible. This prevents the operator from quickly understanding the complete causal link between the observed phenomenon and the resulting image. This paper investigates how a simulation and visualization application of such an instrument, may help users bridge the gap between their mental and the conceptual models of the instrument by displaying an approximation of its internal state in real time. This is supported by a study with 10 microscopists who had to perform a series of plausible tasks on the interface and answer questions. The study shows that users have a better understanding of the instrument's inner state while using the user interface. These results will help software designers develop the next generation of scientific instrument tools.

CCS CONCEPTS

• **Computer systems organization** → Real-time systems; • **Software and its engineering** → Software usability; Software design engineering; Software design tradeoffs; Software prototyping; •

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Human-centered computing → Human computer interaction (HCI); User models; Field studies; Empirical studies in HCI.

KEYWORDS

Mental Model, Conceptual Model, Simulation Visualization, Interface Scientific Instrument, Education

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The inner workings of a transmission electron microscope (TEM) are complex[9, 10] due to a large number of components and their interactions as well as the opaqueness of the instrument (the trajectory of the electron's beam is impossible to measure during acquisition). This limits both experts and novices in understanding and exploring new configurations [15]. This global interpretability[12, 17] issue arises because while it is possible to understand individual steps leading to the output, it is impossible to have a comprehensive understanding of the entire process while using the microscope. When interacting with the microscope, users develop a mental model[6, 8] of the instrument. Such models are often oversimplified and not always accurate[3, 6, 7] but should converge toward conceptual models with training[14]. However, the conceptual models developed in electron microscopy[18] often rely on information inaccessible to the user such as the shape of the electron beam. We think it is preventing this convergence. In this paper, we propose using a real-time simulation[5] with a visualization and interaction

interface to provide insights into the global effects of changing the instrument’s parameters, bridging the gap between mental and conceptual models. As a result, this paper aims to answer: What is included in the mental and conceptual model of an electron microscope? ; Can a visualization and simulation tool for an electron microscope acts as a link between the two models? ; If it can, how can the user correct their mental model using a simulation of an electron microscope?

We present a user interface developed at CEMES-CNRS and ENAC to simulate a TEM and facilitate user interaction. Through questionnaires and tasks, we assess participants’ mental models before and during software use, evaluate the interface’s effectiveness in linking mental and conceptual models, and analyze the impact on mental model accuracy.

1 CONTEXT

The paper uses the definitions of mental and conceptual models based on the works of Norman[14] and Greca[6]. A mental model is described as an implicit, imprecise, unscientific, yet functional and dynamic representation that individuals create unconsciously to simulate the behavior of an object and interact with it efficiently. In the context of an electron microscope, mental models should be formed based on the user’s interaction with the instrument and the type of feedback received, such as the image on the screen. Research suggests that having a valid mental model leads to improved performance[6], while a shared mental model benefits team performance[2]. On the other hand, conceptual models are precise, complete, scientific external representations that are shared within a specific community[15], often created by theoreticians for teaching and knowledge sharing. However, conceptual models can be biased towards theory and may overlook practical difficulties[13]. For instance, teaching material for transmission electron microscopy typically includes representations of electron trajectories, even though these trajectories are not directly visible and must be inferred from the resulting image and configuration parameters. Ideally, mental models of TEMs should converge towards conceptual models[14], but this disparity proves challenging to overcome in the context of a TEM.

This poster focuses on a simulation of a Transmission Electron Microscope (TEM) owned by the tCEMES-CNRS laboratory. TEMs are used to study the properties of matter at nanometric or atomic scales[9]. A powerful beam of electrons is directed onto a sample using electromagnetic lenses, resulting in an enlarged image of the observed object. Theoretical and practical training is required to use a TEM effectively, the first focuses on the path of the electrons inside the TEM (cf fig 2, left) which is not visible nor accessible during the experiment while the other is concerned with successive steps to get the best-resulting image (cf fig 2, right). Although these steps are based on the conceptual model, users often struggle to connect theoretical knowledge with the practical use of the microscope. If users had visibility of the beam and other inaccessible information, it would provide valuable insights into the microscope’s operation.

2 STUDY

We devised a study to extract the mental model and conceptual model perception of a TEM by 10 microscopists, each during an

individual one-hour-long session. The study had also the goal to study how these mental models adapted to the use of a visualization and interaction interface to a simulation of their instrument.

The process of the experiment is described 3. The main study tasks included aligning the beam on the sample and reconstructing the image on the screen. Task order followed the typical TEM configuration for better participant understanding. Participants were encouraged to vocalize their actions, and recordings were made for analysis. The interviewer also observed the participants’ attitudes and use of controls. Consent forms were obtained, and anonymity was ensured.

The SimuTEM interface was developed using a participatory approach[4, 11, 16]. The resulting interface (fig 1 on the left) features a visualization of the microscope’s internal processes, parameter adjustment boxes, and simulated beam representation. It also allowed viewing of the simulated image on multiple panels along the optical axis. Key features desired by users included a representation aligned with the conceptual model (F1), proximity between user actions and effects (F2), real-time configuration changes with feedback (F3), and coherence with physics (F4). To maintain the real-time criterion, a fast simulation using the paraxial approximation was chosen over existing simulation software. The whole experiment was synthesized for each participant in one document. Thematic analysis inspired by Braun and Clark[1] was then performed on that synthesis to extract patterns in the answers and behaviors of the participants. To understand the microscopists’ mental models, we asked them to describe the step-by-step process of performing a basic operation on the TEM. The vocabulary used in their responses was categorized into conceptual model-related terms and terms associated with practical microscope use. We observed their reactions during the tasks to assess their understanding of each step and how they incorporated knowledge of the conceptual model. The interface provided insights into beam trajectory and enabled comparisons between participants’ mental models before and after using the interface. For comparison, we used the usual representation of TEM configurations in the literature as well as a question aimed at bringing the core purpose of the electron microscope: “How would you describe the TEM to a 12-year-old boy?” When the interviewer detected a problem in the participant’s mental model that was preventing them from completing a task successfully or if it took too long to complete, some cues were given explaining the theory required to solve the task or what sub-task could be helpful.

3 RESULTS

We assigned a number at random to each participant; they will be referred to as PX, where X is their participant number.

For the mental model, we first extracted and analyzed the vocabulary used to determine whether it was most directly linked to the image as expected or to the conceptual model used for teaching purposes. It was linked mostly to the former with examples such as “area of interest” P6, “Magnify, demagnify, focusing, defocusing” P2, even more so if we interpret ambiguous language such as “beam” or “alignment” which come from the theoretical representations but are used in place of their effect on the output image as in “disperse the beam” P3 or “alignment more or less good” P5. P8 described a

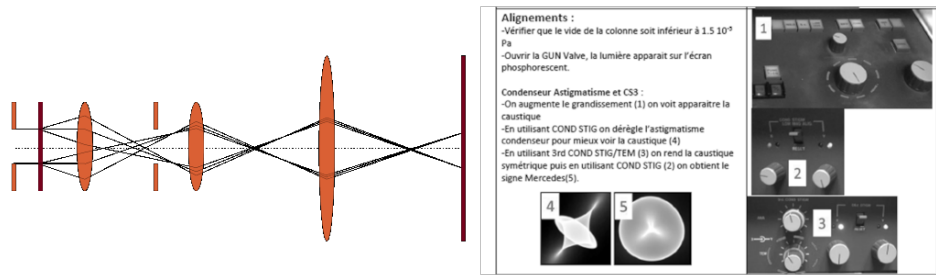


Figure 2: An example of a conceptual model of a TEM configuration (left) and a set of instructions for aligning the microscope that we expect to be closer to their users’ mental models of a TEM (right).

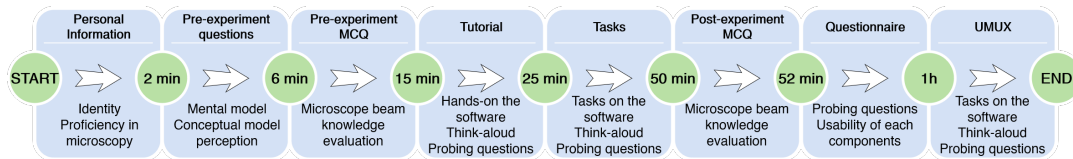


Figure 3: Timeline of an experiment session

list of tasks closely related to the practical training document (fig 2). During the experiment, they were more likely to make connections between the conceptual models and the tasks, as evidenced by sentences like "I was looking for the crossover smoothing but I was more focused on the screen." P7, "I want the crossover to be on the back focal plane of C3" P6, "the closer the crossover is (the smaller) the sample (is)" P7, "it (the beam) seems parallel" P8 or "we want the crossover to be in the plane" P8.

Opposite to the mental model extraction question, for the conceptual model, the participants used a mix of vocabulary, mostly focusing on the inner dynamics of the TEM and the electron trajectories, more in line with the conceptual model. P2 refers to "shooting electrons," P6 refers to "hitting a small or thin sample," P2 refers to "electron passes through," P4 refers to "the light goes through," and P3 refers to "going into thinner material". We finally notice the use of light microscope analogies for many participants (P9, P7, P6, P5, P3).

During the experiment, the interviewer was able to detect errors in the participants’ reasoning and assist them in understanding what they were doing incorrectly. For example, several participants had difficulty remembering that they needed the beam to focus on the back focal plane of the next lens for a parallel beam. Finally, almost all of the participants relied too heavily on the displayed image for the trap but the interviewer just had to explain the issue for them to solve it. The trap was that they needed to enlarge the image of the beam with a lens but they had to first make the image smaller and which is counter-intuitive. useful for alignment tasks, accentuating the unfamiliarity of the simulation.

4 CONCLUSION

We developed an interface that provides microscopists and trainees with a simulated visualization of the internal workings of their instruments. Before using the software, we found that participants

had weak connections between their mental models and the conceptual model of the instrument. However, the study demonstrated that the interface facilitated the linking of concepts from the conceptual model to the participants’ mental models developed through microscope usage. We were also able to identify and address misconceptions about TEM, although further research is needed to assess the long-term learning impact. Based on our findings, we recommend creating interfaces that are based on the instrument’s conceptual model, exhibit physical coherence, and enable direct and instantaneous manipulation by the user. Such interfaces would provide direct access to the theoretical aspects of the instrument, benefiting users in various contexts, including advanced exploration and training. The representation would also be valuable for theorists, facilitating easier sharing of information.

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