Short Note

Priori Justification in Engineering Innovations: Using Computer Simulation Results without Validation to Accelerate Engineering Innovations and Discovery

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Posted Date: 23 June 2023

doi: 10.20944/preprints202306.1656.v1

Keywords: engineering innovation; computer simulation; computational engineering; priori justification doi:10.20944/preprints202306.1656.v1

Priori justification in engineering Innovations: Using computer simulation results without validation to accelerate engineering innovations and discovery

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Abstract: Computer simulation relies on well-defined experimental supported theories, models, and numerical methods. Computer simulation is an alternative to fill the gaps where the experiment is pricy or limited in engineering. Computer simulation is a high-fidelity computational technique that can work as an engineering innovation tool to try imaginative ideas beyond the available technologies. The accuracy of current computer simulation results is reliable enough to accelerate innovation for new materials and mechanical technologies without experimental validation. So, we may need to urge relying on computer simulation results without any experimental validation to accelerate engineering innovations. In addition, using high-fidelity computer simulation for engineering innovation acceleration without validation will be promoted if it is credited as a new classification. This subject and a related justification's classification in engineering have been discussed and introduced.

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Background and Discussion

Computational engineering is a general title for complex engineering systems covering various multiscale multiphysics numerical, analytical, and data-driven methods. Multiscale multiphysics numerical computer simulation methods are high-fidelity computational techniques. Computational engineering is a relatively new and rapidly growing multidisciplinary field that applies advanced computational methods and analysis to engineering practice. It involves developing and applying algorithms, software, and simulations, often with high-performance computing, to translate mathematical and physical descriptions of engineering problems into computer languages. Computational engineering is increasingly important in various fields of academics and industries, such as materials [1–9], manufacturing [10–19], aerospace [20–24], healthcare [25–30], robotics [31–34], etc. Obviously, there is a long list of published computer simulation results showing the importance of computational engineering. Computer simulation relies on well-defined experimental supported theories, models, and numerical methods. Therefore, pushing computer simulations without validation to accelerate innovation could be an acceptable level of trust in computational engineering capabilities.

Generally speaking, our first step to learning is the examination and observation of the behavior of physical events around us. Then the second step could be to formulate the observed event behaviors by a mathematical model. This model development needs mathematical tools, and this mathematical model would primarily be used to describe and summarize the behavior of the event related to a few input stimuli. This model could also be used to predict situations beyond the observed events if the input stimuli change. Modeling is the construction of algebra formulas. If this mathematical model could describe a wide range of behaviors of related physical events, that would be a theory, e.g., Newton's second law (its different forms), density functional theory of first principle quantum calculation, and conservative equations (figure 1). So far, everything starts from experimental evidence or natural observation (experimental methods).

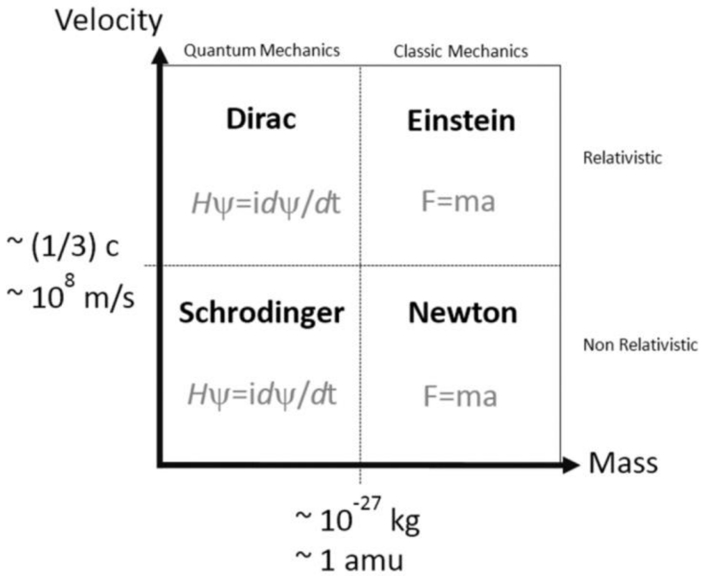

Figure 1. Developed physical formulas and theories according to the mass and velocity of the under-consideration system.

If the theory sets up and solves for simple or simplified physical events, we may be able to have some predictions. Suppose we need to apply the theory to a complex situation or an event to describe the behavior as close as the actual situation. In that case, the theory needs to be solved numerically by computer. Simulation, as another level of investigation method, is a virtual laboratory experience by computer and numerical methods to solve the analytical and theoretical equations describing the underlying complex physical systems.

In summary, we use the so-called experimental, modeling, and simulation methods to learn, model, predict, and design in engineering. Although researchers and engineers emphasize experimental, modeling, and simulation techniques, they prefer to accept simulation results if validated by experiment. Computer simulation is a numerical solution of the well-defined experiment-based developed theoretical models and theories. So, it seems the computer simulation setup is already validated at some level of accuracy. Computer simulation and computational engineering is in progress day by day. The current simulation technologies show promising capabilities to predict trends of complex engineering systems. Therefore, computer simulation could be a tool for examining our imaginative engineering ideas, at least at the early stages. In conclusion, the virtual perception of reality by advanced computer simulation methods would have reliable enough for some engineering predictions and innovations and it can be used to bypass the limitations and high expenses of experimental setups in engineering innovations.

Computer simulation without validations is not suitable for the final version of engineering and ready-to-application designs. And a validated accuracy of computational results would be needed for designing any final product.

We can revisit the research and development methods in engineering (experimental, modeling, and simulation methods) to highlight and promote the capabilities of computer simulation without validation and its benefits for accelerating engineering predictions and innovations. On what was mentioned, probably having a different view would be helpful and more practical if we have a classification based on the justifications in engineering as priori, posteriori, and mixed justifications instead of or in addition to modeling, simulation, and experimental methods.

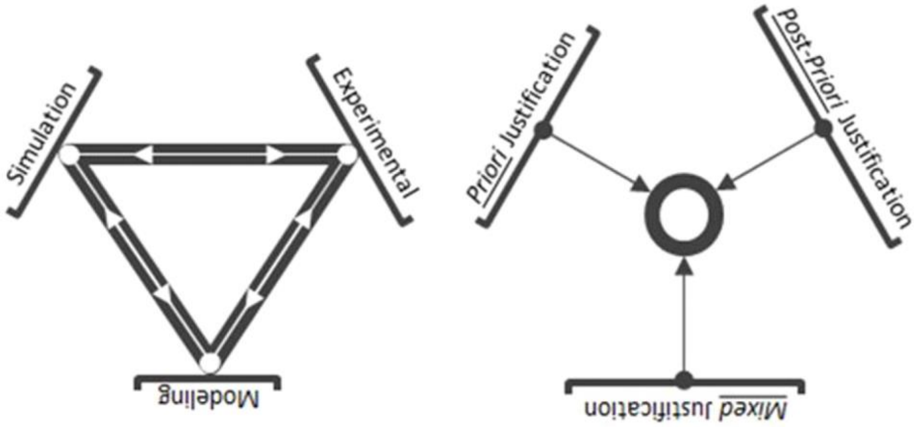

Figure 2. Left) classification based on research technique, Right) classification based on a kind of justification.

A priori justification is for the cases if there is no argument based on an experiment to achieve a rational cognition [35, 36]. Some recent advanced simulation methods could be placed in this category such as first principle quantum mechanics calculation with density functional theory for designing engineering materials. In comparison, post-priori justification refers to the cognition achieved through pure experimental techniques and approaches. The last one indicates a mix of the two earlier-mentioned approaches. In this classification, there is no relation between approaches; we just need to select one of them to do engineering research, and the priori justification has its independence. So, each approach could independently be promoted, and computer simulation without validation would be classified as a priori justification.

The simulation method can give us deeper engineering insight and accelerate engineering innovations, working like a compass. Leonardo da Vinci expresses this subject in a clever sentence, "He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may cast." Nowadays, without a doubt, computer simulation, with or without experimental validations, will help researchers and engineers to decode and demystify scientific and engineering puzzles better, wiser, and faster [37].

If all computer simulations are forced to be validated in engineering, we impose a significant barrier to accelerating engineering predictions and innovations by computer simulation. Suppose the underlying physical events of the engineering system have been supported by well-defined theoretical models; it is a fair claim that computer simulation can be used for engineering predictions and innovations without validations (a priori justification) [38]. A validated computer simulation will be needed if we are looking for an engineering design for the final application (a validated computer simulation would be a mixed justification). Lastly, suppose there are no well-defined theories for the engineering system. In that case, whether the final design or innovations are the goals, experimental studies (a posteriori justification) must be performed first to develop the models, theories, and computational platform. So, priori, posteriori, and mixed justifications cover all situations we encounter in engineering.

Summary

In summary, if computer simulation methods in engineering innovations are credited without validations, the benefits in the acceleration of engineering innovations will be more than the wrong predictions and errors. And the priori, posteriori, and mixed justifications could highlight computational engineering and computer simulation without validation as priori justification.

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