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# Enhancing Graphical Understanding of Statistical Distributions in Physics: Integrating Project-Based Learning with Desmos and Excel: A Case Study of Sixth-Semester Physics Education Students at FKIP Universitas Mataram

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**Abstract:** This study explores the integration of project-based learning with Desmos and Excel to enhance the comprehension of statistical distributions among sixth-semester physics education students at FKIP Universitas Mataram. Employing a mixed-methods approach, combining quantitative assessments with qualitative observations, the research evaluates the effectiveness of Desmos in facilitating statistical understanding within the physics domain. Through structured projects, students engage in data collection, analysis, and interpretation, utilizing Desmos for visualization and exploration of statistical concepts. The findings reveal a significant advantage of Desmos over Excel, with notably higher average scores (85.67 for Desmos compared to 76.33 for Excel) and lower deviation (7.03 for Desmos compared to 8.57 for Excel). This underscores Desmos' efficacy in enhancing students' graphical understanding of statistical distributions. The study underscores the potential of integrating Desmos into project-based learning to cultivate deeper comprehension and engagement in physics education among sixth-semester students at FKIP Universitas Mataram.

**Keywords:** Project-based approach, Desmos, statistical distribution, Maxwell-Boltzmann, Bose-Einstein, Fermi-Dirac, physics education, technology integration, mixed-methods.

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## Introduction

Statistical physics provides a vital approach to comprehending complex natural phenomena, such as the behavior of matter at atomic and molecular scales, thermodynamic properties, and the behavior of many-particle systems. For sixth-semester physics education students in the Department of Mathematics and Natural Sciences Education, Faculty of Teacher Training and Education, Universitas Mataram, understanding these concepts is crucial. Statistical distributions like Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein offer profound insights into the particle behavior within diverse physical systems. Despite its importance, statistical physics has received limited attention in physics education research and remains a relatively underrepresented topic even in research on upper-division physics courses (Koerfer, Ebba; Gregorcic, Bor,2023). This study aims to provide a valuable contribution to the field of statistical physics by emphasizing the learning of statistical distribution concepts such as Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac distributions through a graphical comprehension approach. By utilizing graphical representations, the research seeks to deepen understanding and facilitate comprehension of these complex concepts, thereby enriching the scholarly discourse in the field of statistical physics.

The Maxwell-Boltzmann distribution elucidates the distribution of classical particles, such as atoms or molecules, in thermal equilibrium. This distribution is applicable to particles that are distinguishable from one another and do not adhere to the principles of quantum mechanics. It illustrates the likelihood of locating

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particles in different energy states at a specific temperature. In this distribution, particles are assumed to be non-interacting and can occupy any energy state without any restrictions. The Maxwell-Boltzmann distribution is commonly employed in classical thermodynamics to elucidate the behavior of ideal gases and other systems where quantum effects are negligible. The Maxwell-Boltzmann distribution is a hallmark of statistical physics in thermodynamic equilibrium linking the probability density of a particle's kinetic energies to the temperature of the system that also determines its configurational fluctuations (Su, Xiaoya; Fischer, Alexander and Frank, Cichos, 2021)

The Bose-Einstein distribution is employed to describe the distribution of indistinguishable particles known as bosons, which includes particles like photons, gluons, and specific types of atoms. It adheres to Bose-Einstein statistics and allows multiple bosons to occupy the same quantum state, a characteristic behavior due to their integer spin and exemption from the Pauli exclusion principle. Particularly significant at low temperatures, the Bose-Einstein distribution can lead to phenomena such as Bose-Einstein condensation, characterized by a macroscopic number of particles occupying the lowest energy state. This phenomenon has garnered significant attention in quantum condensed matter physics, especially following the 1995 discovery of Bose-Einstein condensation for practically ideal atomic gases. The theoretical foundation of Bose-Einstein statistics is robust, relying on the combinatorial symmetry of the many-particle wave function concerning the transposition of particle-pair coordinates (Spałek Józef, 2020).

Indistinguishable elements in the origins of quantum statistics are highlighted in the case of Fermi–Dirac statistics (P´ereza, Enric and Ib´a˜nezb, Joana, 2021). The Fermi-Dirac distribution is employed to describe the distribution of indistinguishable particles called fermions, including electrons, protons, and neutrons. These particles adhere to Fermi-Dirac statistics and are governed by the Pauli exclusion principle, which prohibits the simultaneous occupation of the same quantum state by two fermions. This distribution delineates the probability of locating fermions in different energy states at a specific temperature. Crucially, the Fermi-Dirac distribution plays a significant role in elucidating the electronic properties of materials such as metals, semiconductors, and insulators, especially at absolute zero temperature. At this temperature, fermions occupy energy states up to a designated energy level known as the Fermi level, influencing the formation of Fermi surfaces.

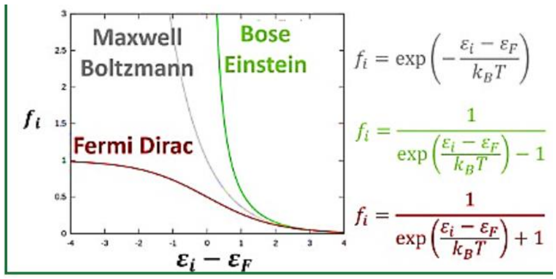



**Figure 1.** Statistical Distribution

Understanding statistical physics, especially the concepts surrounding statistical distribution, is often perceived as challenging by students, necessitating the adoption of project-based learning models. Furthermore, the integration of project-based learning (PBL) methodologies offers a transformative approach to enhancing statistical physics instruction (Ayu et al., 2024; L Sari, 2020; Wahyudi, 2021). PBL stimulates students to actively engage in problem-solving activities, thereby fostering deeper comprehension and critical thinking skills. Through real-world applications and project-based tasks, students not only acquire theoretical knowledge but also develop practical skills essential for their future careers. Empirical studies have consistently demonstrated the efficacy of project-based learning in enhancing student motivation and academic performance in physics education.

In light of the foundational importance of statistical physics, students often encounter difficulties in interpreting complex statistical graphs, necessitating the implementation of effective teaching strategies and tools to enhance their graph comprehension skills. Graphs serve as invaluable tools for summarizing data, facilitating the processing and interpretation of complex information. Understanding graphical representations is crucial because they offer easily understandable quantitative information, which is often more accessible than data presented in descriptive sentences (Yennita et al., 2023).

In response to this pedagogical challenge, educators are diligently exploring innovative methods to enrich the teaching of statistical physics. A promising avenue is the incorporation of technology tools into physics education, with Desmos Graphing Calculator standing out for its advanced graphing capabilities (Nurhayati & Gunawan, 2022, Sihite et all, 2023, Tumamggor, 2024).

By integrating Desmos into the educational framework, educators can foster an interactive and immersive learning atmosphere, thereby facilitating a deeper comprehension of statistical distributions and their graphical representations among students.

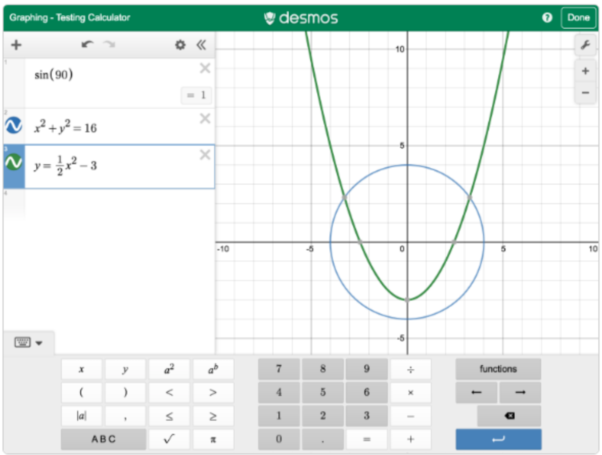



**Figure 2.** Desmos Display Menu

The emergence of Desmos as a powerful educational tool has revolutionized the teaching and learning of physics, particularly in graph comprehension and visualization. This tool has a transformative impact on improving graph comprehension skills and enhancing student learning outcomes in physics education. It provides valuable insights into the practical applications of Desmos within the classroom setting, showcasing its remarkable ability to foster student engagement and cultivate conceptual mastery.

Through empirical research and meta-analyses, scholars underscore the efficacy of Desmos as a potent educational tool in optimizing learning outcomes in Statistical Physics. Longitudinal studies further substantiate the benefits of integrating Desmos into the educational milieu, revealing its pivotal role in nurturing graph comprehension skills over time and bolstering students' conceptual development. Additionally, comparative analyses accentuate Desmos' superiority vis-à-vis other software tools in facilitating interactive learning experiences and promoting deeper conceptual understanding in Physics Education.

Furthermore, the integration of Desmos into the pedagogical framework also allows for personalized learning experiences tailored to students' individual needs and learning styles. Through Desmos' intuitive interface and customizable features, educators can create interactive graphing activities and simulations that cater to diverse learning preferences. This personalized approach not only enhances student engagement but also fosters a deeper understanding of complex statistical concepts.

In addition to technological advancements, fostering collaboration between educators, researchers, and developers is crucial for the continuous improvement and refinement of educational technology tools like Desmos. By fostering a collaborative ecosystem, stakeholders can exchange insights, share best practices, and co-create innovative solutions to address evolving challenges in Physics Education. Through ongoing collaboration and innovation, the integration of Desmos and project-based learning methodologies can continue to advance the field of Statistical Physics education, ultimately enhancing student learning outcomes and preparing them for success in the ever-changing world of physics.

The synergy between project-based learning and Desmos not only enhances students' understanding of statistical physics but also fosters their critical thinking and problem-solving skills, essential for their future careers in the scientific field. By engaging in hands-on projects and utilizing Desmos for graphing and analysis, students develop a deeper appreciation for the practical applications of statistical physics concepts in real-world scenarios. This holistic approach to education not only empowers students with theoretical knowledge but also equips them with the practical skills necessary to tackle complex scientific challenges.

## Method

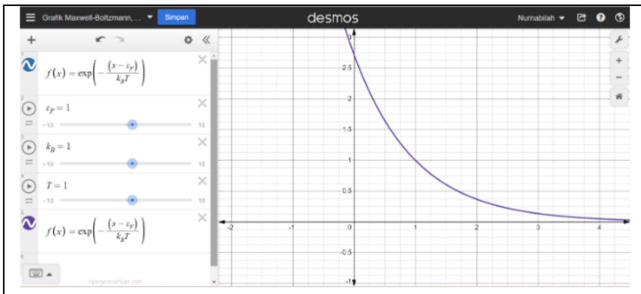
This study employs an experimental research design to investigate the effectiveness of Excel and Desmos in enhancing students' comprehension of creating statistical physics distribution graphs. The research population consists of a single group of students, subdivided into two treatment conditions. The initial session utilizes Excel as the primary software tool for graph creation, while the subsequent session employs Desmos. Before the intervention, students undertake a pre-test to gauge their baseline understanding of crafting distribution graphs using Excel.

Following the initial session, students receive training focused on Excel's functionalities for graph creation. The second session centers on utilizing Desmos for the same purpose. Post-intervention, students undergo a post-test to evaluate the advancement in their understanding, with the results presented in Figure 7. Only post-test results are displayed, highlighting the progress achieved through the interventions.

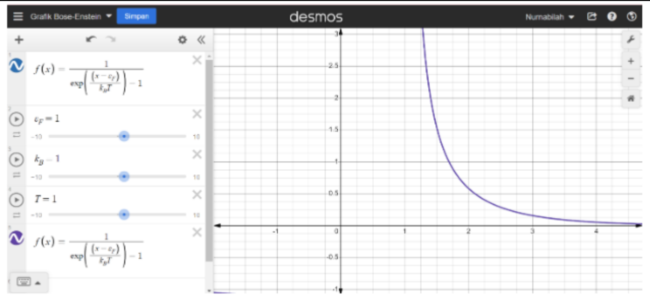
Pre-test and post-test data are subjected to rigorous statistical analysis to compare the progression in students' comprehension between Excel and Desmos usage. Additionally, outside lecture hours, students are assigned extended group discussion tasks, with submissions due within one week. During the subsequent session, their submissions are discussed to assess their comprehension and application of the learned concepts.

## Result and Discussion

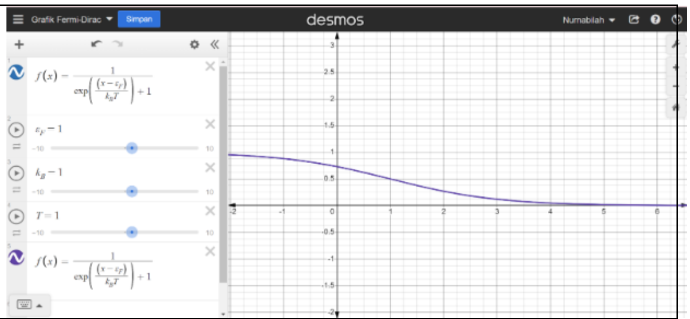
The findings of this study highlight the graphical representations successfully produced by the students, as illustrated in Figures 3, 4, 5, and 6.



Graph 3. Maxwel Boltman Distribution on Desmos



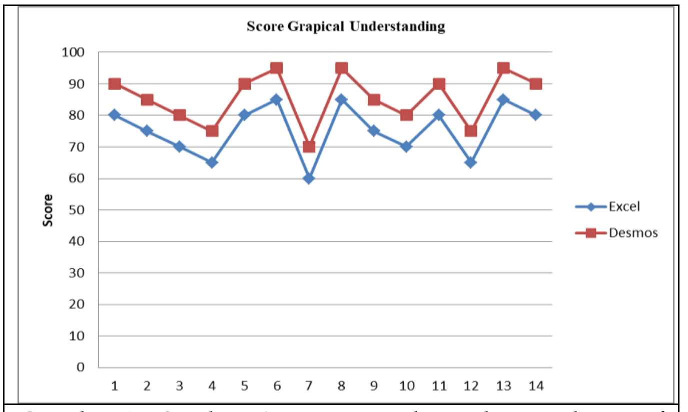
Graph 4. Bose Einstein Distribution on Desmos



Graph 5. Fermi Dirac Distribution on Desmos

Graph 6. **Maxwell-Boltzma, Bose-Enstein dan Fermi-Dirac on Desmos**

The findings on students' mastery of graphical concepts using Excel and Desmos are succinctly summarized in graph 7 of this study. The graph presents a comprehensive overview of students' scores and assessments, facilitating a comparative analysis of their performance across both software platforms.



Graph 7. Students' conceptual understanding of graphical distributions

Based on the graph 7 provided, illustrating the scores depicting students' graphical understanding of statistical distributions using both Excel and Desmos, several discernible patterns emerge. Primarily, the average score attained with Desmos (85.67) significantly surpasses that of Excel (76.33), indicating a pronounced superiority in performance among students utilizing Desmos.

This disparity in average scores suggests a potentially heightened efficacy of Desmos in augmenting students' comprehension of statistical distributions compared to Excel. Furthermore, the lower deviation observed with Desmos (7.03) compared to Excel (8.57) implies a greater consistency or diminished variability in scores amongst students employing Desmos.

This underscores the notion that Desmos furnishes a more standardized and reliable platform for students to grasp statistical concepts graphically. Additionally, a recurring trend emerges across individual scores, with Desmos consistently yielding higher scores compared to Excel. These findings collectively suggest the preferential suitability of Desmos as a tool for enhancing students' graphical understanding of statistical distributions with Excel.

However, conducting further qualitative analyses and soliciting student feedback would serve to elucidate the underlying rationales for these disparities and to delineate their practical implications for educational pedagogy.

## Conclusion

The findings of this study underscore the synergistic benefits of integrating Desmos and Excel, along with the PBL model, in enhancing students' graphical understanding of statistical physics distributions. Through the utilization of Desmos, students were provided with dynamic graphing capabilities and interactive features that significantly contributed to their engagement and comprehension of complex statistical concepts. The higher average scores and lower deviation observed in the Desmos data compared to Excel suggest a clear advantage in utilizing Desmos for graphical comprehension. Additionally, the integration of the PBL model facilitated collaborative problem-solving and critical thinking skills, further enriching students' learning experiences. These findings highlight the importance of incorporating innovative software tools like Desmos alongside traditional methods like Excel, within the framework of pedagogical approaches such as PBL, to foster deeper conceptual understanding and analytical proficiency among students in the field of statistical physics education. This integrated approach holds promising implications for curriculum development and instructional practices, emphasizing the need to adapt and evolve educational strategies to meet the diverse learning needs of students in the digital age.

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