PERKULIAHAN PERSAMAAN DIFERENSIAL BIASA MENGGUNAKAN *COMPUTER AIDED DESIGN* UNTUK MENINGKATKAN KETERAMPILAN BERPIKIR KRITIS DAN KEMAMPUAN PEMECAHAN MASALAH MAHASISWA

DISERTASI

Diajukan untuk Memenuhi Sebagian dari Syarat Memperoleh Gelar
Doktor Pendidikan Ilmu Pengetahuan Alam

Oleh
Sujito
NIM 1803367

PROGRAM STUDI DOKTOR PENDIDIKAN ILMU PENGETAHUAN ALAM
FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM
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**PERKULIAHAN PERSAMAAN DIFERENSIAL BIASA MENGGUNAKAN
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MAHASISWA**

Oleh

Sujito

Dr. Pendidikan IPA Universitas Pendidikan Indonesia, 2023
M.Si. Ilmu Fisika-Optoelektronika Institut Teknologi Sepuluh Nopember Surabaya, 2007
S.Pd. Pendidikan Fisika Universitas Negeri Malang, 1999

Sebuah Disertasi yang diajukan untuk memenuhi salah satu syarat memperoleh
gelar Doktor Pendidikan (Dr.) di Fakultas Matematika dan Ilmu Pengetahuan Alam

LEMBAR PENGESAHAN

SUJITO

PERKULIAHAN PERSAMAAN DIFERENSIAL BIASA MENGGUNAKAN COMPUTER
AIDED DESIGN UNTUK MENINGKATKAN KETERAMPILAN
BERPIKIR KRITIS DAN KEMAMPUAN PEMECAHAN MASALAH MAHASISWA

disetujui dan disahkan oleh panitia Disertasi

Promotor

Prof.Dr. Liliasari, M.Pd.
NIPT.920191119490927201

Ko-promotor
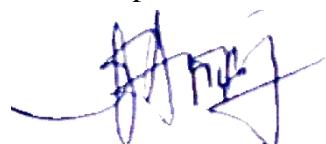
Prof.Dr.Andi Suhandi, S.Pd, M.Si
NIP.196908171994031003

Anggota

Prof. Dr. Edy Soewono, M.Si.
NIDK.1952062620221420

Mengetahui
Ketua Program Studi Pendidikan Ilmu Pengetahuan Alam
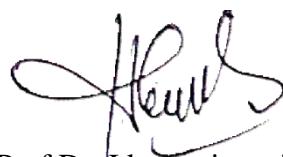
Prof.Dr. Ida Kaniawati, M.Si
NIP.196807031992032001

PERNYATAAN

Dengan ini saya menyatakan bahwa disertasi yang berjudul "**PERKULIAHAN PERSAMAAN DIFERENSIAL BIASA MENGGUNAKAN *COMPUTER AIDED DESIGN* UNTUK MENINGKATKAN KETERAMPILAN BERPIKIR KRITIS DAN KEMAMPUAN PEMECAHAN MASALAH MAHASISWA**" beserta seluruh isinya adalah benar-benar karya sendiri dan saya tidak melakukan penjiplakan atau pengutipan dengan cara-cara yang tidak sesuai dengan etika keilmuan yang berlaku. Atas pernyataan ini, saya siap menanggung sanksi tindakan hukum yang dijatuhkan kepada saya apabila di kemudian hari ditemukan adanya pelanggaran terhadap etika keilmuan dalam karya saya.

Bandung,   Agustus 2023
Yang membuat pernyataan,

Sujito
NIM. 1803367

KATA PENGANTAR

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Pentingnya melatih keterampilan berpikir kritis dan kemampuan pemecahan masalah bagi mahasiswa Pendidikan IPA dalam menghadapi era Revolusi Industri 4.0 dan tantangan global yang kompleks dan dinamis menjadi latar belakang penulisan disertasi ini. Di era digital saat ini, kemampuan berpikir kritis dan kemampuan pemecahan masalah menjadi keterampilan yang dibutuhkan dalam menghadapi perubahan yang cepat dan kompleks di dunia kerja. Dalam konteks Revolusi Industri 4.0, di mana teknologi dan informasi berkembang pesat, mahasiswa perlu memiliki kemampuan untuk menghadapi tantangan baru dan mengambil keputusan yang tepat dengan berdasarkan pemikiran yang kritis dan rasional.

Perkuliahan Persamaan Diferensial Biasa Menggunakan *Computer Aided Design* (CAD) menjadi salah satu pendekatan yang efektif dalam melatih keterampilan berpikir kritis dan kemampuan pemecahan masalah. Dengan memadukan konten dan perkembangan teknologi terkini, mahasiswa dapat mengalami pengalaman belajar yang menantang dan mendalam. Pendalaman perangkat lunak Maple membantu mahasiswa dalam mengakses sumber daya pembelajaran yang relevan dan mendukung pengembangan keterampilan berpikir kritis dan kemampuan pemecahan masalah.

Penulis mengakui adanya berbagai keterbatasan dan kekurangan dalam penulisan disertasi ini. Penulis sangat mengharapkan umpan balik yang konstruktif untuk memperbaiki dan menyempurnakan penulisan disertasi ini. Penulis mengapresiasi segala kritik dan saran yang disampaikan, serta berterima kasih atas perhatian yang diberikan. Semoga upaya penyempurnaan penelitian ini dapat memberikan manfaat dan kontribusi yang lebih besar dalam pengembangan ilmu khususnya dalam pembelajaran IPA.

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ABSTRAK

Keterampilan berpikir kritis memiliki peran penting dan esensial bagi mahasiswa dalam menyelesaikan masalah untuk mempersiapkan diri menghadapi tantangan dunia nyata serta kekompleksan akademik. Penggunaan *Computer-Aided Design* (CAD) dengan *software* Maple dalam perkuliahan Persamaan Diferensial Biasa terbukti dapat memfasilitasi peningkatan keterampilan berpikir kritis dan kemampuan pemecahan masalah mahasiswa. Metode penelitian adalah *mixed methods* dengan desain *embedded experimental model.* Penelitian uji coba skala kecil di universitas negeri di Bandung melibatkan 42 mahasiswa dan implementasi program pada universitas negeri di Malang menjadi kelompok kontrol (51 orang) dan eksperimen (55 orang). Pengumpulan data kuantitatif menggunakan instrumen tes yang terintegrasi dengan materi PDB untuk keterampilan berpikir kritis berbentuk pilihan ganda (11 soal) dan kemampuan pemecahan masalah dalam bentuk essai (4 soal). Pengumpulan data kualitatif dilakukan dengan pengamatan, skala sikap dan wawancara. Data dianalisis secara kuantitatif, kualitatif dan analisa gabungan. Hasil penelitian menunjukkan peningkatan keterampilan berpikir kritis mahasiswa pada kategori sedang. Indikator membangun keterampilan dasar mengalami peningkatan tertinggi, dan terendah pada indikator mengatur strategi dan taktik. Pada kemampuan pemecahan masalah, semua indikator mengalami peningkatan pada kategori sedang. Peningkatan tertinggi pada indikator Mathematical procedure dan terendah pada useful description. Software Maple memberi pengaruh positif dengan kategori sedang ($d = 0,70$) dalam memfasilitasi capaian keterampilan berpikir kritis, dan kategori sedang ($d = 0,68$) pada kemampuan pemecahan masalah. Keunggulan adalah pembelajaran dilakukan lebih interaktif dan mampu memvisualkan persamaan, mengeksplorasi topik perkuliahan lebih mendalam, dan melatih keterampilan mahasiswa untuk berpikir lebih kritis dalam memecahkan permasalahan. Keterbatasannya yaitu mahasiswa mempunyai kendala menentukan variabel-variabel yang berpengaruh pada proses fisika, ketika berhadapan dengan fenomena fisika. Karakteristik perkuliahan adalah menggunakan pendekatan berbasis masalah, mampu mengintegrasikan perkembangan ilmu pengetahuan dan teknologi dalam pembelajaran, dan mampu meningkatkan keterampilan berpikir kritis.

Kata kunci: pdb, cad, maple, keterampilan berpikir kritis, pemecahan masalah

ABSTRACT

Critical thinking skills have a significant and essential role for students in solving problems to prepare themselves for real-world challenges and academic complexities. Computer-Aided Design (CAD) with Maple software in Ordinary Differential Equations courses improves students' critical thinking and problem-solving abilities. The research method is mixed methods with an embedded experimental model design. A small-scale pilot study at a state university in Bandung involved 42 students, and program implementation at a state university in Malang was divided into control (51 people) and experimental (55 people) groups. Quantitative data collection uses a test instrument integrated with PDB material for critical thinking skills in multiple-choice (11 questions) and problem-solving abilities in the form of essays (4 questions). Qualitative data was collected by observation, attitude scale, and interviews. Data were analyzed quantitatively, qualitatively, and combined analysis. The results showed an increase in students' critical thinking skills in the medium category. The indicator for building basic skills experienced the highest increase and the lowest for the indicator for managing strategy and tactics. In problem-solving abilities, all indicators have increased in the medium category. The highest increase was in the Mathematical procedure indicator, and the lowest was in the useful description. Maple Software positively influences the moderate category ($d = 0.70$) in facilitating the achievement of critical thinking skills and the medium category ($d = 0.68$) in problem-solving abilities. The advantage is that learning is done more interactively and can visualize equations, explore lecture topics more deeply, and train students' skills to think more critically in solving problems. The limitation is that students need help determining the variables that affect physical processes when dealing with physical phenomena. The characteristics of lectures are using a problem-based approach, being able to integrate scientific and technological developments in learning, and being able to improve critical thinking skills.

Keywords: ODE, CAD, maple, critical thinking skills, problem solving

DAFTAR ISI

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DAFTAR GAMBAR

DAFTAR LAMPIRAN

DAFTAR PUSTAKA

Abdullah, S., & Shariff, A. (2008). The effects of inquiry-based computer simulation with cooperative learning on scientific thinking and conceptual understanding of gas laws. *Eurasia Journal of Mathematics, Science and Technology Education*, *4*(4), 387–398.

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 Meta-Analysis. *Review of Educational Research*, *78*(4), 1102–1134. https://doi.org/10.3102/0034654308326084

Achmetli, K., Schukajlow, S., & Rakoczy, K. (2019). Multiple Solutions for Real-World Problems, Experience of Competence and Students' Procedural and Conceptual Knowledge. *International Journal of Science and Mathematics Education*, *17*(8), 1605–1625. https://doi.org/10.1007/s10763-018-9936-5

Adams, W. K., & Wieman, C. E. (2015). Analyzing the many skills involved in solving complex physics problems. *American Journal of Physics*, *83*(5), 459–467. https://doi.org/10.1119/1.4913923

Adri, M., Rusdinal, Zainul, R., Darni, Sriadhi, Wahyuningtyas, N., Khaerudin, Nasrun, Rahmulyani, Nuranjani, Nurmaniah, Wedi, A., Surahman, E., Aisyah, E. N., Oktaviani, H. I., Sri Martini Meilanie, R., Purnamawati, S. N., Hapidin, Listyasari, W. D., … Adnan, E. (2020). Development of Content Learning System in Professional Education Subjects for Educational Institutions in Indonesia. *Journal of Physics: Conference Series*, *1594*(1). https://doi.org/10.1088/1742-6596/1594/1/012022

Ainsworth, S. E. (1999). The Functions of Multiple Representations. *Computers & Education*, *33*, 131–152.

Ainsworth, S. E. (2006). DeFT: A Conceptual Framework for Considering Learning with Multiplerepresentation. *Learning and Instruction*, *16*, 183–198.

Ali, M., Talib, C.-A., Hasniza Ibrahim, N., Surif, J., & Halim Abdullah, A. (2016). The Importance of Monitoring Skills in Physics Problem Solving. *European Journal of Education Studies*, *1*(3), 1–10.

Alpaslan, M. M., Yalvac, B., Loving, C. C., & Willson, V. (2016). Exploring the Relationship Between High School Students' Physics-Related Personal Epistemologies and Self-regulated Learning in Turkey. *International Journal of Science and Mathematics Education*, *14*(2), 297–317. https://doi.org/10.1007/s10763-015-9685-7

Alsina, Á., & Salgado, M. (2021). Understanding Early Mathematical Modelling: First Steps in the Process of Translation Between Real-world Contexts and Mathematics. *International Journal of Science and Mathematics Education*, 1719–1742. https://doi.org/10.1007/s10763-021-10232-8

Anagün, Ş. S. (2018). Teachers' perceptions about the relationship between 21st century skills and managing constructivist learning environments. *International*

Journal of Instruction, *11*(4), 825–840. https://doi.org/10.12973/iji.2018.11452a

Anggraena, Y., Felicia, N., G, D. E., Pratiwi, I., Utama, B., Alhapip, L., & Widiaswati, D. (2021). Kajian Akademik Kurikulum Untuk Pemulihan Pembelajaran. *Pusat Kurikulum Dan Pembelajaran Badan Standar, Kurikulum, Dan Asesmen Pendidikan Kementerian Pendidikan, Kebudayaan, Riset, Dan Teknologi*, 123. https://repositori.kemdikbud.go.id/20029/1/Buku Merdeka Belajar 2020.pdf

Anggrianto, D., Churiyah, M., & Arief, M. (2016). Improving Critical Thinking Skills Using Learning Model Logan Avenue Problem Solving (LAPS)-Heuristic. *Journal of Education and Practice*, *7*(9), 128–136.

Argaw, A. S., Haile, B. B., Ayalew, B. T., & Kuma, S. G. (2017). The effect of problem based learning (PBL) instruction on students' motivation and problem solving skills of physics. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(3), 857–871. https://doi.org/10.12973/eurasia.2017.00647a

Bahri, A., Jamaluddin, A. B., Muharni, A., Fikri, M. J. N., & Arifuddin, M. (2021). The Need of Science Learning to Empower High Order Thinking Skills in 21st Century. *Journal of Physics: Conference Series*, *1899*(1). https://doi.org/10.1088/1742-6596/1899/1/012144

Bajracharya, R. R., & Thompson, J. R. (2016). Analytical derivation : An epistemic game for solving mathematically based physics problems. *Physical Review Physics Education Research*, *12*(1), 010124(1-21). 10.1103/PhysRevPhysEducRes.12.010124

Bani-Hamad, A. M. H., & Abdullah, A. H. (2019). Developing Female Students' Learning and Innovation Skills (4cs) In Physics through Problem Based Learning. *International Journal of Academic Research in Business and Social Sciences*, *9*(12), 501–513. https://doi.org/10.6007/IJARBSS/v9-i12/6750

Barak, M. (2017). Science Teacher Education in the Twenty-First Century: a Pedagogical Framework for Technology-Integrated Social Constructivism. *Research in Science Education*, *47*(2), 283–303. https://doi.org/10.1007/s11165-015-9501-y

Barak, M. (2020a). Problem-, Project- and Design-Based Learning: Their Relationship to Teaching Science, Technology and Engineering in School. *Journal of Problem-Based Learning*, *7*(2), 94–97. https://doi.org/10.24313/jpbl.2020.00227

Barak, M. (2020b). Problem-, Project- and Design-Based Learning: Their Relationship to Teaching Science, Technology and Engineering in School. *J Probl Based Learn*, *7*(2), 94–97. https://doi.org/10.24313/jpbl.2020.00227

Barret, T. (2017). A New Model of Problem-Based Learning: Inspiring Concepts, Practice Strategies and Case Studies from Higher Education. In *The British Journal of Psychiatry* (Vol. 111, Issue 479).

Bartley, J. E., Boeving, E. R., Riedel, M. C., Bottenhorn, K. L., Salo, T., Eickhoff, S. B., Brewe, E., Sutherland, M. T., & Laird, A. R. (2018). Meta-analytic evidence for a core problem solving network across multiple representational domains.

Neuroscience and Biobehavioral Reviews, *92*, 318–337. https://doi.org/10.1016/j.neubiorev.2018.06.009

Barzilai, S., & Eilam, B. (2018). Learners' epistemic criteria and strategies for evaluating scientific visual representations. *Learning and Instruction*, *58,* (March 2017), 137–147. https://doi.org/10.1016/j.learninstruc.2018.06.002

Bayat, S., & Tarmizi, R. A. (2012). Effects of Problem-based Learning Approach on Cognitive Variables of University Students. *Procedia - Social and Behavioral Sciences*, *46*, 3146–3151. https://doi.org/https://doi.org/10.1016/j.sbspro.2012.06.027

Bibi, A., Akmar, S. N., Zamri, S., Abedalaziz, N., Ahmad, M., Norulakmar, S., Abdallah, N., & Abedalaziz, M. (2017). *Teaching and Learning of Differential Equation: A Critical Review to Explore Potential Area for Reform Movement*. *6*, 225–235. https://www.researchgate.net/publication/317953989

Bing, T. J., & Redish, E. F. (2009). Analyzing problem solving using math in physics: Epistemological framing via warrants. *Physical Review Special Topics - Physics Education Research*, *5*(2), 1–15.

Boa, E. A., Wattanatorn, A., & Tagong, K. (2018). The development and validation of the Blended Socratic Method of Teaching (BSMT): An instructional model to enhance critical thinking skills of undergraduate business students. *Kasetsart Journal of Social Sciences*, *39*(1), 81–89. https://doi.org/10.1016/j.kjss.2018.01.001

Boas, M. L. (2006). *Mathematical methods in The Physical Sciences* (3rd ed.). John Wiley & Sons, Inc. https://doi.org/10.2307/2275199

Boud, D., & Dawson, P. (2021). What feedback literate teachers do: an empirically-derived competency framework. *Assessment & Evaluation in Higher Education*, 1–14. https://doi.org/10.1080/02602938.2021.1910928

Boyce, W. E., Trahan, D. H., & DiPrima, R. C. (2017). Elementary Differential Equations and Boundary Value Problems. In *The American Mathematical Monthly* (Vol. 86, Issue 7).

Brahmia, S. W., Olsho, A., Smith, T. I., Boudreaux, A., Eaton, P., & Zimmerman, C. (2021). Physics Inventory of Quantitative Literacy: A tool for assessing mathematical reasoning in introductory physics. *Physical Review Physics Education Research*, *17*(2), 20129. https://doi.org/10.1103/PhysRevPhysEducRes.17.020129

Branchetti, L., Cattabriga, A., & Levrini, O. (2019). Interplay between mathematics and physics to catch the nature of a scientific breakthrough: The case of the blackbody. *Physical Review Physics Education Research*, *15*(2), 20130. https://doi.org/10.1103/PhysRevPhysEducRes.15.020130

Caballero, M. D., Doughty, L., Turnbull, A. M., Pepper, R. E., & Pollock, S. J. (2017). Assessing learning outcomes in middle-division classical mechanics: The Colorado Classical Mechanics and Math Methods Instrument. *Physical Review Physics Education Research*, *13*(1), 1–12. https://doi.org/10.1103/PhysRevPhysEducRes.13.010118

Ceuppens, S., Deprez, J., Dehaene, W., & De Cock, M. (2018). Design and validation of a test for representational fluency of 9th grade students in physics and mathematics: The case of linear functions. *Physical Review Physics Education Research*, *14*(2), 20105. https://doi.org/10.1103/PhysRevPhysEducRes.14.020105

Chang, C., Chang, M. H., Chiu, B. C., Liu, C. C., Fan Chiang, S. H., Wen, C. T., Hwang, F. K., Wu, Y. T., Chao, P. Y., Lai, C. H., Wu, S. W., Chang, C. K., & Chen, W. (2017). An analysis of student collaborative problem solving activities mediated by collaborative simulations. *Computers and Education*, *114*(300), 222–235. http://dx.doi.org/10.1016/j.compedu.2017.07.008

Chassy, P., & Jones, J. (2019). The role of mathematics in the learning of physics. *Journal of Mathematical and Theoritical Physics*, *2*(1), 8–10. https://medcraveonline.com/OAJMTP/OAJMTP-02-00045.pdf

Chung, P., Yeh, R. C., & Chen, Y.-C. (2016). Influence of problem-based learning strategy on enhancing student's industrial oriented competences learned: an action research on learning weblog analysis. *International Journal of Technology and Design Education*, *26*(2), 285–307. https://doi.org/10.1007/s10798-015-9306-3

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). Applied multiple regression/correlation analysis for the behavioral sciences. In *Lawrence Erlbaum Associates Publishers* (3rd ed.). Lawrence Erlbaum Associates Publishers.

Costa, A. L. (1991). Developing Minds. In *Developing Minds: A Resource Book for Teaching Thiinking* (Revised, V). ASCD Publications.

Creswell, J. W. (2017). *RESEARCH DESIGN: Qualitative, Quantitative, and Mixed Methods Approaches* (5th Ed.). SAGE Publications, Inc.

Cross, D., Taasoobshirazi, G., Hendricks, S., & Hickey, D. T. (2008). Argumentation: A strategy for improving achievement and revealing scientific identities. *International Journal of Science Education*, *30*(6), 837–861. https://doi.org/10.1080/09500690701411567

Czocher, J. A. (2017). The Journal of Mathematical Behavior How can emphasizing mathematical modeling principles benefit students in a traditionally taught differential equations course? *Journal of Mathematical Behavior*, *45*, 78–94. https://doi.org/10.1016/j.jmathb.2016.10.006

Dahal, K. (2006). *Problem-Based Learning: New Paradigm in Teaching-Learning Process in the University What is Problem Based Learning? The objectives of PBL Development of PBL in Education* (1st ed.). Tri-Chandra Multiple Campus.

Danvers, E. (2018). Who is the critical thinker in higher education? A feminist re-thinking. *Teaching in Higher Education*, *23*(5), 548–562. https://doi.org/10.1080/13562517.2018.1454419

Dell'Era, C., Magistretti, S., Cautela, C., Verganti, R., & Zurlo, F. (2020). Four kinds of design thinking: From ideating to making, engaging, and criticizing. *Creativity and Innovation Management*, *29*(2), 324–344. https://doi.org/10.1111/caim.12353

Deprez, T., Gijsen, S. E., Deprez, J., & De Cock, M. (2019). Investigating student understanding of cross products in a mathematical and two electromagnetism contexts. *Physical Review Physics Education Research*, *15*(2), 20132. https://doi.org/10.1103/PhysRevPhysEducRes.15.020132

Devy Alvionita, Prabowo, & Z.A. Imam Supardi. (2020). Problem Based Learning With The SETS Method To Improve The Student's Critical Thinking Skill of Senior High School. *IJORER : International Journal of Recent Educational Research*, *1*(3), 246–260. https://doi.org/10.46245/ijorer.v1i3.46

Didiş Körhasan, N., & Hldlr, M. (2019). How should textbook analogies be used in teaching physics? *Physical Review Physics Education Research*, *15*(1), 1–8. https://doi.org/10.1103/PhysRevPhysEducRes.15.010109

Ding, L. (2019). Theoretical perspectives of quantitative physics education research. *Physical Review Physics Education Research*, *15*(2), 20101. https://doi.org/10.1103/PhysRevPhysEducRes.15.020101

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics - Physics Education Research*, *10*(2), 1–58.

Doran, Y. J. (2017). The role of mathematics in physics: Building knowledge and describing the empirical world. *Onomazein*, *35*, 209–226.

Dounas-Frazer, D. R., Van De Bogart, K. L., Stetzer, M. R., & Lewandowski, H. J. (2016). Investigating the role of model-based reasoning while troubleshooting an electric circuit. *Physical Review Physics Education Research*, *12*(1), 1–20. https://doi.org/10.1103/PhysRevPhysEducRes.12.010137

Duch, B. J., Groh, S. E., & Allen, D. E. (2010). *The Power of Problem Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline.* Stylus Publishing LLC.

Dunne, G. (2015). Beyond critical thinking to critical being: Criticality in higher education and life. *International Journal of Educational Research*, *71*, 86–99. https://doi.org/10.1016/j.ijer.2015.03.003

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*, 43–52. https://doi.org/10.1016/j.tsc.2013.12.004

Ennis, R. H. (1996). Critical Thinking. In *Printece Hall Inc.* (5th ed.). Printece Hall Inc. https://doi.org/10.1111/j.0021-8774.2005.00541.x

Erol, M., & Çolak, İ. Ö. (2020). Mathematical modelling of electrical potential difference in a non-uniform electric field. *Momentum: Physics Education Journal*, *4*(2), 64–72.

Ersoy, E., & Başer, N. (2014). The Effects of Problem-based Learning Method in Higher Education on Creative Thinking. *Procedia - Social and Behavioral Sciences*, *116*, 3494–3498. https://doi.org/10.1016/j.sbspro.2014.01.790

Eshach, H., & Kukliansky, I. (2018). University Physics and Engineering Students' Use of Intuitive Rules, Experience, and Experimental Errors and Uncertainties.

International Journal of Science and Mathematics Education, *16*(5), 817–834. https://doi.org/10.1007/s10763-017-9817-3

Fang, N., & Guo, Y. (2016). Interactive computer simulation and animation for improving student learning of particle kinetics. *Journal of Computer Assisted Learning*, *1*(February), 1–13.

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers and Education*, *142*(July), 103635. https://doi.org/10.1016/j.compedu.2019.103635

Foley, G. (2020). Introduction: The state of adult education and learning. *Dimensions of Adult Learning: Adult Education and Training in a Global Era*, 3–18. https://doi.org/10.4324/9781003115366-2

Gewurtz, R. E., Coman, L., Dhillon, S., Jung, B., & Solomon, P. (2016). Problem-based Learning and Theories of Teaching and Learning in Health Professional Education. *Journal of Perspective in Applied Academic Practice*, *4*(1), 59–70.

Gifford, J. D., & Finkelstein, N. D. (2020). Categorical framework for mathematical sense making in physics. *Physical Review Physics Education Research*, *16*(2), 20121. https://doi.org/10.1103/PhysRevPhysEducRes.16.020121

Glyzin, S. D., & Kolesov, A. Y. (2022). On a Method of Mathematical Modeling of Electrical Synapses. *Differential Equations*, *58*(7), 853–868. https://doi.org/10.1134/S0012266122070011

Goedbloed, H. P., & Poedts, S. (2004). *Principles of Magnetohydrodynamics* (2nd ed.). Cambridge University Press, The Edinburgh Building, Cambridge CB2 8RU,UK. www.cambridge.org/9780521623476

Good, M., Maries, A., & Singh, C. (2019). Impact of traditional or evidence-based active-engagement instruction on introductory female and male students' attitudes and approaches to physics problem solving. *Physical Review Physics Education Research*, *15*(2), 20129. https://doi.org/10.1103/PhysRevPhysEducRes.15.020129

Goodhew, L. M., Robertson, A. D., Heron, P. R. L., & Scherr, R. E. (2019). Student conceptual resources for understanding mechanical wave propagation. *Physical Review Physics Education Research*, *15*(2), 20127. https://doi.org/10.1103/PhysRevPhysEducRes.15.020127

Gosper, M., & Ifenthaler, D. (2014). *Curriculum Models for the 21st Century* (M. Gosper (ed.)). Springer International Publishing AG. https://doi.org/10.1007/978-1-4614-7366-4

Greca, I. M., & Moreira, M. A. (2002). Mental, Physical, and Mathematical Models in the Teaching and Learning of Physics. *Science Education*. https://doi.org/10.1002/sce.10013

Greca, I. M., Seoane, E., & Arriassecq, I. (2014). Epistemological Issues Concerning Computer Simulations in Science and Their Implications for Science Education. *Science and Education*, *23*(4), 897–921. 10.1007/s11191-013-9673-7

Greiff, S., Wüstenberg, S., Csapó, B., Demetriou, A., Hautamäki, J., Graesser, A. C., & Martin, R. (2014). Domain-general problem solving skills and education in the 21st century. *Educational Research Review*, *13*, 74–83. https://doi.org/10.1016/j.edurev.2014.10.002

Guisasola, J., & Zuza, K. (2020). *Challenges in Physics Education*. Springer Nature Switzerland AG.

Gunawan, G., Harjono, A., Nisyah, M., Kusdiastuti, M., & Herayanti, L. (2020). Improving students' problem-solving skills using inquiry learning model combined with advance organizer. *International Journal of Instruction*, *13*(4), 427–442. https://doi.org/10.29333/iji.2020.13427a

Hackemann, T., Heine, L., & Höttecke, D. (2022). Challenging to Read, Easy to Comprehend? Effects of Linguistic Demands on Secondary Students' Text Comprehension in Physics. *International Journal of Science and Mathematics Education*, *20*, 43–68. https://doi.org/10.1007/s10763-022-10306-1

Hadjiachilleos, S., Valanides, N., & Angeli, C. (2013). The impact of cognitive and affective aspects of cognitive conflict on learners' conceptual change about floating and sinking. *Research in Science and Technological Education*, *31*(2), 133–152. https://doi.org/10.1080/02635143.2013.811074

Hamerski, P. C., McPadden, D., Caballero, M. D., & Irving, P. W. (2022). Students' perspectives on computational challenges in physics class. *Physical Review Physics Education Research*, *18*(2), 20109. https://doi.org/10.1103/PhysRevPhysEducRes.18.020109

Hashemi, H., Shaharoun, A. M., Izman, S., & Kurniawan, D. (2014). Recent Developments on Computer Aided Fixture Design: Case Based Reasoning Approaches. *Advances in Mechanical Engineering*, *2014*(484928), 15. https://doi.org/10.1155/2014/484928

Heller, K., & Heller, P. (2010). Cooperative Problem Solving in Physics A User's Manual Can this be True? In *University of Minnesota* (1st ed.). University of Minnesota. http://www.physics.umn.edu/groups/physed

Ho, H. N. J., & Liang, J. C. (2015). The Relationships Among Scientific Epistemic Beliefs, Conceptions of Learning Science, and Motivation of Learning Science: A study of Taiwan high school students. *International Journal of Science Education*, *37*(16), 2688–2707. https://doi.org/10.1080/09500693.2015.1100346

Hong, H. Y., Chen, B., & Chai, C. S. (2016). Exploring the development of college students' epistemic views during their knowledge building activities. *Computers and Education*, *98*, 1–13. https://doi.org/10.1016/j.compedu.2016.03.005

Hong, J., Hwang, M.-Y., Szeto, E., Tai, K.-H., & Tsai, C.-R. (2021). Undergraduate Science Students' Scientist–Practitioner Gap: the Role of Epistemic Curiosity and Cognitive Flexibility. *International Journal of Science and Mathematics Education*, *19*(5), 899–913. https://doi.org/10.1007/s10763-020-10096-4

Hu, D., Chen, K., Leak, A. E., Young, N. T., Santangelo, B., Zwickl, B. M., & Martin, K. N. (2019). Characterizing mathematical problem solving in physics-related workplaces using epistemic games. *Physical Review Physics Education*

Research, *15*(2), 20131. https://doi.org/10.1103/PhysRevPhysEducRes.15.020131

Hua, S. J. (2010). The Application of the Multimedia Technology in Teaching Introduction to Tourism. *Advanced Materials Research*, *994*, 124–126. https://doi.org/10.1109/MVHI.2010.109

Huang, N. T. N., Chiu, L. J., & Hong, J. C. (2016). Relationship Among Students' Problem-Solving Attitude, Perceived Value, Behavioral Attitude, and Intention to Participate in a Science and Technology Contest. *International Journal of Science and Mathematics Education*, *14*(8), 1419–1435. https://doi.org/10.1007/s10763-015-9665-y

Hughes-Hallett, D., McCallum, W. G., Gleason, A. M., & Connally, E. (2018). *Calculus* (E. J. Marks (ed.); 7th ed.). John Wiley & Sons, Inc. www.wiley.com/go/citizenship

Ince, E. (2018). An Overview of Problem Solving Studies in Physics Education. *Journal of Education and Learning*, *7*(4), 191–200. https://doi.org/10.5539/jel.v7n4p191

Ismail, N. S., Harun, J., Zakaria, M. A. Z. M., & Salleh, S. M. (2018). The effect of Mobile problem-based learning application DicScience PBL on students' critical thinking. *Thinking Skills and Creativity*, *28*, 177–195. https://doi.org/10.1016/j.tsc.2018.04.002

Jazby, D., Widjaja, W., Xu, L., & van Driel, J. H. (2022). Noticing student thinking under pressure in primary mathematics and science lessons. *International Journal of Science and Mathematics Education*, 645–666. https://doi.org/10.1007/s10763-022-10263-9

Jensen, J. H., Niss, M., & Jankvist, U. T. (2016). Problem solving in the borderland between mathematics and physics. *International Journal of Mathematical Education in Science and Technology*, *5211*(September), 1–15. http://dx.doi.org/10.1080/0020739X.2016.1206979

Johnson, P., & Almuna, F. (2022). *The role of problem context familiarity in modelling first-order ordinary differential equations*. *13*(2), 323–336.

Jones, S. R. (2015). Areas, anti-derivatives, and adding up pieces: Definite integrals in pure mathematics and applied science contexts. *Journal of Mathematical Behavior*, *38*, 9–28. http://dx.doi.org/10.1016/j.jmathb.2015.01.001

Journal, C., & West, B. H. (2018). *Teaching Differential Equations without Computer Graphics Solutions is a Crime Graphics Solutions is a Crime* . *11*(2016).

Kalimbetov, B., & Kulakhmetova, S. (2022). Teaching and learning differential equations in engineering studies by using low-level CAS commands. *World Transactions on Engineering and Technology Education*, *20*(2), 118–123. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85131448272&partnerID=40&md5=3298c51c35ca2191970ebac7a685781b

Kang, H., Scharmann, L. C., Kang, S., & Noh, T. (2010). Cognitive Conflict and Situational Interest as Factors Influencing Conceptual Change. *International*

Journal of Environmental and Science Education, *5*(4), 383–405. http://www.eric.ed.gov/ERICWebPortal/detail?accno=EJ908938%5Cnhttp://www.eric.ed.gov/PDFS/EJ908938.pdf

Karam, R. (2014). Framing the structural role of mathematics in physics lectures: A case study on electromagnetism. *Physical Review Special Topics - Physics Education Research*, *10*(1), 1–23.

Keefe, P. A. O., Letourneau, S. M., Homer, B. D., Schwartz, R. N., & Plass, J. L. (2014). Computers in Human Behavior Learning from multiple representations : An examination of fixation patterns in a science simulation. *Computers in Human Behavior*, *35*, 234–242. http://dx.doi.org/10.1016/j.chb.2014.02.040

Kim, K., Sharma, P., Land, S. M., & Furlong, K. P. (2013). Effects of Active Learning on Enhancing Student Critical Thinking in an Undergraduate General Science Course. *Innovative Higher Education*, *38*(3), 223–235. https://doi.org/10.1007/s10755-012-9236-x

Kim, N. J., Belland, B. R., & Walker, A. E. (2018). Effectiveness of Computer-Based Scaffolding in the Context of Problem-Based Learning for Stem Education: Bayesian Meta-analysis. *Educational Psychology Review*, *30*(2), 397–429. https://doi.org/10.1007/s10648-017-9419-1

King, F. J., Goodson, L., Rohani, F., Level, D. K., Plan, Q. E., Oliver, S., Seniwoliba, J. A., Yakubu, •Richard Nalarb, Lee, D., Student, A., Tasks, P., Tan, S. Y., Halili, S. H., Bloom, B., Swartz, R., McGuinness, C., Bell, E., Allen, R., Brennan, P., … Order, H. (2015). Improving students' higher-order thinking competencies, including critical evaluation, creative thinking, and reflection on their own thinking. *Research in Science Education*, *3*(2), 1–41. https://doi.org/10.1007/s11165-006-9029-2

Kjeldsen, T. H., & Lu, J. (2015). Interactions Between Mathematics and Physics: The History of the Concept of Function - Teaching with and About Nature of Mathematics. *Science & Education*, *16*. http://10.0.3.239/s11191-015-9746-x

Kjeldsen, T. H., & Lützen, J. (2015). Interactions Between Mathematics and Physics: The History of the Concept of Function—Teaching with and About Nature of Mathematics. *Science and Education*, *24*(5–6), 543–559.

Klein, P., Dengel, A., & Kuhn, J. (2018). Students' Visual Attention While Solving Multiple Representation Problems in Upper-Division Physics An Eye Tracking Study. In O. Z.-T. Et (Ed.), *Positive Learning in the Age of Information* (pp. 67–87). Springer Fachmedien Wiesbaden GmbH. https://doi.org/10.1007/978-3-658-19567-0_6

Klein, P., Ivanjek, L., Dahlkemper, M. N., Jeličić, K., Geyer, M. A., Küchemann, S., & Susac, A. (2021). Studying physics during the COVID-19 pandemic: Student assessments of learning achievement, perceived effectiveness of online recitations, and online laboratories. *Physical Review Physics Education Research*, *17*(1), 1–11. https://doi.org/10.1103/PhysRevPhysEducRes.17.010117

Klein, P., Viiri, J., & Kuhn, J. (2019). Visual cues improve students' understanding

of divergence and curl: Evidence from eye movements during reading and problem solving. *Physical Review Physics Education Research*, *15*(1), 10126. https://doi.org/10.1103/PhysRevPhysEducRes.15.010126

Kneubil, F. B., & Robilotta, M. R. (2015). Physics Teaching: Mathematics as an Epistemological. *Science & Education*, *1*. http://10.0.3.239/s11191-014-9727-5

Kohnle, A., & Passante, G. (2017). Characterizing representational learning: A combined simulation and tutorial on perturbation theory. *Physical Review Physics Education Research*, *13*(2), 1–13. https://doi.org/10.1103/PhysRevPhysEducRes.13.020131

Kosel, B., Celinsek, D., Kustrin, I., Djuric, M., & Jarc, M. (2005). *Guide to Problem-Based Learning-PBL within the Context of ESP*. Ljubljana: Slovene Association of LSP Teachers Please.

Kumari, M. (2019). *Optimizing the Problem Solving in Ordinary Differential Equations using MATLAB. 14*(2), 556–559.

Kuo, E., Hallinen, N. R., & Conlin, L. D. (2017). When procedures discourage insight: epistemological consequences of prompting novice physics students to construct force diagrams. *International Journal of Science Education*, *0693*(April), 1–26. www.tandfonline.com/loi/tsed20

Kustusch, M. B. (2014). Partial derivative games in thermodynamics : A cognitive task analysis. *PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH*, *010101*(10), 1–16.

Kwatra, B., & Mudgil, M. (2020). *Untangling the Mathematical Relation Between Natural Selection and Adaptive Radiation Using Macromolecules and Microevolutionary Forces. 7*(2), 313–339.

Legresley, S. E., Delgado, J. A., Bruner, C. R., Murray, M. J., & Fischer, C. J. (2019). Calculus-enhanced energy-first curriculum for introductory physics improves student performance locally and in downstream courses. *Physical Review Physics Education Research*, *15*(2), 20126. https://doi.org/10.1103/PhysRevPhysEducRes.15.020126

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). Design and Design Thinking in STEM Education. *Journal for STEM Education Research*, *2*(2), 93–104. https://doi.org/10.1007/s41979-019-00020-z

Liliasari. (2009). *Keterampilan Berpikir Kritis Dalam Pembelajaran Sains Kimia Menuju Profesionalitas Guru*. http://file.upi.edu/Direktori/SPS/PRODI

Lin, T., Chen, V., & Chai, C. S. (2015). *New Media and Learning in the 21st Century*. Springer Science+Business Media B.V., part of Springer Nature.

Liu, Y., Shen, F., & Yang, Y. (2019). Numerical Simulation on the Propagation and Deflection of Fast Coronal Mass Ejections (CMEs) Interacting with a Corotating Interaction Region in Interplanetary Space. *The Astrophysical Journal*, *887*(2), 150. https://doi.org/10.3847/1538-4357/ab543e

Lloyd, M., & Bahr, N. (2010). Thinking critically about critical thinking in higher

education. *International Journal for the Scholarship of Teaching and Learning*, *4*. https://doi.org/Article

Lu, Y., Yin, Q., Li, H., Sun, H., Yang, Y., & Hou, M. (2020). Solving higher order nonlinear ordinary differential equations with least squares support vector machines. *Journal of Industrial and Management Optimization*, *16IS-3S*, 1502. https://doi.org/10.3934/jimo.2019012

Major, T., & Mulvihill, T. M. (2018). Problem-based learning pedagogies in teacher education: The case of Botswana. *Interdisciplinary Journal of Problem-Based Learning*, *12*(1). https://doi.org/10.7771/1541-5015.1543

Malmia, W., Makatita, S. H., Lisaholit, S., Azwan, A., Magfirah, I., Tinggapi, H., & Umanailo, M. C. B. (2019). Problem-based learning as an effort to improve student learning outcomes. *International Journal of Scientific and Technology Research*, *8*(9), 1140–1143.

Mann, L., Chang, R., Chandrasekaran, S., Coddington, A., Daniel, S., Cook, E., Crossin, E., Cosson, B., Turner, J., Mazzurco, A., Dohaney, J., O'Hanlon, T., Pickering, J., Walker, S., Maclean, F., & Smith, T. D. (2021). From problem-based learning to practice-based education: a framework for shaping future engineers. *European Journal of Engineering Education*, *46*(1), 27–47. https://doi.org/10.1080/03043797.2019.1708867

Marra, R. M., Jonassen, D. H., Palmer, B., & Luft, S. (2014). Why Problem-Based Learning Works : Theoretical Foundations. *Journal of Excellence in College Teaching*, *25*, 221–238.

Marzano, R. J., & Kendall, J. S. (2007). *Praise for the Second Edition of The New Taxonomy of Educational Objectives*. Corwin Press A Sage Publications Company.

Matthee, M., & Turpin, M. (2019). Teaching critical thinking, problem solving, and design thinking: Preparing IS students for the future. *Journal of Information Systems Education*, *30*(4), 242–252.

Miri, B., David, B. C., & Uri, Z. (2007). Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in Science Education*, *37*(4), 353–369. https://doi.org/10.1007/s11165-006-9029-2

Mkhatshwa, T. P. (2023). Differential equations: students' reasoning about a problem posing task. *International Journal of Mathematical Education in Science and Technology*, 1–20. https://doi.org/10.1080/0020739X.2022.2162454

Moust, J., Bouhuijs, P., & Schmidt, H. (2021). Introduction to Problem-Based Learning (4th ed.). In *Routledge* (4th ed., Vol. 4th). Routledge. https://doi.org/https://doi.org/10.4324/9781003194187

Mumba, F., Rutt, A., & Chabalengula, V. M. (2023). Representation of Science and Engineering Practices and Design Skills in Engineering Design-Integrated Science Units Developed by Pre-service Teachers. *International Journal of Science and Mathematics Education*, *21*(2), 439–461. https://doi.org/10.1007/s10763-022-10266-6

Nardini, J. T., Baker, R. E., Simpson, M. J., & Flores, K. B. (2021). *Learning differential equation models from stochastic agent-based model simulations*.

Nggadas, D. E. P., & Ariswan, A. (2019). The mastery of physics concepts between students are learning by ICT and laboratory experiments based-teaching. *Momentum: Physics Education Journal*, *2*(1), 21–31. https://doi.org/10.21067/mpej.v3i1.3343

Nielsen, S. S., & Nielsen, J. A. (2019). A Competence-Oriented Approach to Models and Modelling in Lower Secondary Science Education: Practices and Rationales Among Danish Teachers. *Research in Science Education*. https://doi.org/10.1007/s11165-019-09900-1

Niss, M. (2017). Obstacles Related to Structuring for Mathematization Encountered by Students when Solving Physics Problems. *International Journal of Science and Mathematics Education*, *15*(8), 1441–1462. https://doi.org/10.1007/s10763-016-9754-6

Nurzaman. (2017). The Use of Problem-Based Learning Model to Improve Quality Learning Students Morals. *Journal of Ecucation and Practice*, *8*(9), 234–245.

Odden, T. O. B., Lockwood, E., & Caballero, M. D. (2019). Physics computational literacy: An exploratory case study using computational essays. *Physical Review Physics Education Research*, *15*(2), 020152(1-22). https://doi.org/10.1103/PhysRevPhysEducRes.15.020152

Ott, N., Brünken, R., Vogel, M., & Malone, S. (2018). Multiple symbolic representations: The combination of formula and text supports problem solving in the mathematical field of propositional logic. *Learning and Instruction*, *58*(April), 88–105. https://doi.org/10.1016/j.learninstruc.2018.04.010

Palmgren, E., & Rasa, T. (2022). Modelling Roles of Mathematics in Physics: Perspectives for Physics Education. *Science and Education*, *31*(5). https://doi.org/10.1007/s11191-022-00393-5

Paul, R. W. (2012). *Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World* (W. Jan & A. J. A. Binker (eds.); 1st ed.). Foundation for Critical Thingking.

Perez, J. F. S., Conesa, M., & Alhama, I. (2016). Solving ordinary differential equations by electrical analogy : a multidisciplinary teaching tool. *European Journal of Physics*, *37*(6), 1–12. https://doi.org/10.1088/0143-0807/37/6/065703

Permatasari, B. D., Gunarhadi, & Riyadi. (2019). The influence of problem based learning towards social science learning outcomes viewed from learning interest. *International Journal of Evaluation and Research in Education*, *8*(1), 39–46. https://doi.org/10.11591/ijere.v8i1.15594

Petrova, L. P., & Pryadko, I. N. (2022). On Systems of Differential Equations with Constraints in the Form of Not Necessarily Convex Sets. *Differential Equations*, *58*(10), 1309–1317. https://doi.org/10.1134/S00122661220100020

Pierce, J. W., & Jones, B. F. (n.d.). *Problem Based Learning : Learning and Teaching in the Context of Problems*.

Project, P. H., & Bv, O. (2016). ICT in Education : literacy , enhancement and personalization 1. *Unesco Sources*, *September*, 1–24.

Pulgar, J., Candia, C., & Leonardi, P. M. (2020). Social networks and academic performance in physics: Undergraduate cooperation enhances ill-structured problem elaboration and inhibits well-structured problem solving. *Physical Review Physics Education Research*, *16*(1), 10137. https://doi.org/10.1103/PHYSREVPHYSEDUCRES.16.010137

Redfors, A., Hansson, L., Hansson, Ö., & Juter, K. (2013). The Role of Mathematics in The Teaching And Learning of Physics. *Learning Science: Cognitive, Affective and Social Aspects*, *2*, 376–383. https://www.diva-portal.org/smash/get/diva2:710055/FULLTEXT01.pdf

Redish, E. F., & Kuo, E. (2015a). Language of Physics, Language of Math: Disciplinary Culture and Dynamic Epistemology. *Journal of Science & Education*, *15*(7). http://10.0.3.239/s11191-015-9749-7

Redish, E. F., & Kuo, E. (2015b). Language of Physics, Language of Math: Disciplinary Culture and Dynamic Epistemology. *Science and Education*.

Riley, K. F., & Hobson, M. P. (2011). *Foundation Mathematics for the Physical Sciences* (1st ed.). Cambridge University Press, The Edinburgh Building, Cambridge cb2 2ru,UK. www.cambridge.org

Robertson, A. D., Scherr, R. E., Goodhew, L. M., Daane, A. R., Gray, K. E., & Aker, L. B. (2017). Identifying content knowledge for teaching energy: Examples from high school physics. *Physical Review Physics Education Research*, *13*(1), 1–14. 10.1103/PhysRevPhysEducRes.13.010105

Roller, M. R. (2020). A Quality Approach to Qualitative Content Analysis Secondary. In *Qualitative Data Analysis* (p. 29).

Roundy, D., Weber, E., Dray, T., Bajracharya, R. R., Dorko, A., Smith, E. M., & Manogue, C. A. (2015). Experts' understanding of partial derivatives using the partial derivative machine. *Physical Review Special Topics - Physics Education Research*, *020126*(11), 1–21. https://doi.org/10.1103/PhysRevSTPER.11.020126

Rui, K., & Liu, D. (2018). The Importance of Multiple Representations of Mathematical Problems: Evidence from Chinese Preservice Elementary Teachers' Analysis of a Learning Goal. *International Journal of Science and Mathematics Education*, *16*(1), 125–143. https://doi.org/10.1007/s10763-016-9760-8

Ryan, Q. X., Frodermann, E., Heller, K., Hsu, L., & Mason, A. (2016). Computer problem-solving coaches for introductory physics: Design and usability studies. *Physical Review Physics Education Research*, *12*(1), 1–17.

Ryan, Q. X., Wilcox, B. R., & Pollock, S. J. (2018). Student difficulties with boundary conditions in the context of electromagnetic waves. *Physical Review Physics Education Research*, *14*(2), 20126. https://doi.org/10.1103/PhysRevPhysEducRes.14.020126

Sasson, I., Yehuda, I., & Malkinson, N. (2018). Fostering the skills of critical thinking and question-posing in a project-based learning environment. *Thinking Skills and Creativity*, *29*, 203–212. https://doi.org/10.1016/j.tsc.2018.08.001

Savall-Alemany, F., Guisasola, J., Rosa Cintas, S., & Martínez-Torregrosa, J. (2019). Problem-based structure for a teaching-learning sequence to overcome students' difficulties when learning about atomic spectra. *Physical Review Physics Education Research*, *15*(2), 20138. https://doi.org/10.1103/PhysRevPhysEducRes.15.020138

Schermerhorn, B. P., & Thompson, J. R. (2019). Physics students' construction of differential length vectors in an unconventional spherical coordinate system. *Physical Review Physics Education Research*, *15*(1), 10111. https://doi.org/10.1103/PhysRevPhysEducRes.15.010111

Sebatana, M. J., & Dudu, W. T. (2022). Reality or Mirage: Enhancing 21st-Century Skills Through Problem-Based Learning While Teaching Particulate Nature of Matter. *International Journal of Science and Mathematics Education*, *20*(5), 963–980. https://doi.org/10.1007/s10763-021-10206-w

Selcuk, G. S., & Caliskan, S. (2013). a Comparison of Achievement in Problem-Based, Strategic and Traditional Learning Classes in Physics. *International Journal on New Trends in Education and Their*, *January*, 14–1309. www.ijonte.org

Shaaron, A. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198.

Shin, D., & Shim, J. (2021). A Systematic Review on Data Mining for Mathematics and Science Education. *International Journal of Science and Mathematics Education*, *19*(4), 639–659. https://doi.org/10.1007/s10763-020-10085-7

Sijmkens, E., Scheerlinck, N., De Cock, M., & Deprez, J. (2022). Benefits of using context while teaching differential equations. *International Journal of Mathematical Education in Science and Technology*, *53*(3), 1–21. https://doi.org/10.1080/0020739X.2022.2039412

Sin, C. (2014). Epistemology, sociology, and learning and teaching in physics. *Science Education*, *98*(2), 342–365. https://doi.org/10.1002/sce.21100

Smith, T. I., Wittmann, M. C., & Carter, T. (2014). Applying model analysis to a resource-based analysis of the Force and Motion Conceptual Evaluation. *Physical Review Special Topics - Physics Education Research*, *10*(2), 1–17. https://doi.org/10.1103/PhysRevSTPER.10.020102

Smolcic, E., & Arends, J. (2017). Building Teacher Interculturality. *Teacher Education Quarterly*, 51–73.

So, K. (2013). Knowledge construction among teachers within a community based on inquiry as stance. *Teaching and Teacher Education*, *29*, 188–196. https://doi.org/10.1016/j.tate.2012.10.005

Spooner, K. (2022). What does mathematical modelling have to offer mathematics education? Insights from students' perspectives on mathematical modelling.

International Journal of Mathematical Education in Science and Technology, 1–13. https://doi.org/10.1080/0020739X.2021.2009052

Stewart, J. (2016). *Calculus* (8th ed.). Cengage Learning. https://doi.org/10.1103/PhysRevB.38.174

Stiggins, R. (1991). Reviewed Work: Evaluating Critical Thinking by Stephen P. Norris, Robert H. Ennis. *Journal of Educational Measurement*, *28*(4), 355–357. https://doi.org/10.5539/hes.v4n1p1

Stupple, E. J. N., Maratos, F. A., Elander, J., Hunt, T. E., Cheung, K. Y. F., & Aubeeluck, A. V. (2017). Development of the Critical Thinking Toolkit (CriTT): A measure of student attitudes and beliefs about critical thinking. *Thinking Skills and Creativity*, *23*, 91–100. https://doi.org/10.1016/j.tsc.2016.11.007

Suastra, I. W., Ristiati, N. P., Adnyana, P. P. B., & Kanca, N. (2019). The effectiveness of Problem Based Learning - Physics module with authentic assessment for enhancing senior high school students' physics problem solving ability and critical thinking ability. *Journal of Physics: Conference Series*, *1171*(1). https://doi.org/10.1088/1742-6596/1171/1/012027

Suhandi, A., & Wibowo, F. C. (2012). Pendekatan multirepresentasi dalam pembelajaran usaha-energi dan dampak terhadap pemahaman konsep mahasiswa. *Jurnal Pendidikan Fisika Indonesia*, *8*(1).

Suhirman, S., Prayogi, S., & Asy'ari, M. (2021). Problem-Based Learning with Character-Emphasis and Naturalist Intelligence: Examining Students Critical Thinking and Curiosity. *International Journal of Instruction*, *14*(2), 217–232. https://doi.org/10.29333/iji.2021.14213a

Sujito, & Liliasari, S. (2020). Investigation of mathematical methods for physics lecture process at pre-service physics teacher. *Journal of Physics: Conference Series*, *1521*(2).

Sujito, Liliasari, Suhandi, A., & Soewono, E. (2021a). Investigating and Developing The Ability to Model Physics Phenomena. *Journal of Engineering Science and Technology*, *16*(4), 3283–3294. https://jestec.taylors.edu.my/V16Issue4.htm

Sujito, Pratiwi, H. Y., Soewono, E., Suhandi, A., & Liliasari, S. (2021). Views and practices of mathematical method for physics lecture at pre-service physics teachers. *Journal of Physics: Conference Series*, *1806*(1). https://doi.org/10.1088/1742-6596/1806/1/012001

Sujito, S., Liliasari, L., & Suhandi, A. (2021). Differential equations: Solving the oscillation system. *Journal of Physics: Conference Series*, *1869*(1). https://doi.org/10.1088/1742-6596/1869/1/012163

Sujito, S., Liliasari, L., Suhandi, A., & Soewono, E. (2021b). Description in course of mathematical methods for physics and possible development of course program. *Momentum: Physics Education Journal*, *5*(1), 73–84. https://doi.org/10.21067/mpej.v5i1.5184

Sutopo, & Waldrip, B. (2014). Impact of A Representational Approach on Students's Reasoning and Conceptual understanding in Learning Mechanics. *International*

Journal of Science and Mathematics Education, *12*(4), 741–765. https://doi.org/10.1007/s10763-013-9431-y

Taleyarkhan, M., & Dasgupta, C. (2018). Investigating the Impact of Using a CAD Simulation Tool on Students' Learning of Design Thinking. *Journal of Science Education and Technology*, *3*, 1–18. https://doi.org/10.1007/s10956-018-9727-3

Tang, K. T. (2007). *Mathematical Methods for Engineers and Scientists 2*. Springer-Verlag Berlin Heidelberg.

Tang, O. (2003). Problem Based Learning Innovation: Using Problems To Power Learning In The 21st Century. In *Thomson Learning Asia* (Vol. 1). Cengage Learning.

Tania, R., Jumadi, & Astuti, D. P. (2020). The application of physics e-handout assisted by PBL model use Edmodo to improve critical thinking skills and ICT literacy of high school students. *Journal of Physics: Conference Series*, *1440*(1). https://doi.org/10.1088/1742-6596/1440/1/012037

Tim Dosen, F. U. (2020). *2020 KATALOG PRODI S1 PENDIDIKAN FISIKA*. UM Pres.

Tiruneh, D. T., & Cock, M. De. (2018). Designing Learning Environments for Critical Thinking : Examining Effective Instructional Approaches. *International Journal of Science and Mathematic Education*, *16*, 1065–1089. https://doi.org/10.1007/s10763-017-9829-z

Tisdell, C. C. (2017). Improved pedagogy for linear differential equations by reconsidering how we measure the size of solutions reconsidering how we measure the size of solutions. *International Journal of Mathematical Education in Science and Technology*, *48*(7), 1–9. https://doi.org/10.1080/0020739X.2017.1298856

Tolga, G. (2015). An investigation of students' performance after peer instruction with stepwise problem-solving strategies. *International Journal of Science and Mathematics Education*, *13*(3), 561–582.

Treagust, D. F., Chittleborough, G., & Mamiala, T. (2010). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 37–41. https://doi.org/10.1080/0950069032000070306

Treagust, D. F., Duit, R., & Fischer, H. E. (2017). *Multiple Representations in Physics Education*. Springer International Publishing AG.

Tuminaro, J. (2004). A Cognitive Framework For Analyzing And Describing Introductory Students' Use And Understanding Of Mathematics In Physics. *Dissertasi*, *1*(1).

Turner, E. E., Roth McDuffie, A., Bennett, A. B., Aguirre, J., Chen, M.-K., Foote, M. Q., & Smith, J. E. (2022). Mathematical Modeling in the Elementary Grades: Developing and Testing an Assessment. *International Journal of Science and Mathematics Education*, *20*(7), 1387–1409. https://doi.org/10.1007/s10763-021-10195-w

Ubuz, B., & Erdoğan, B. (2019). Effects of Physical Manipulative Instructions with or without Explicit Metacognitive Questions on Geometrical Knowledge Acquisition. *International Journal of Science and Mathematics Education*, *17*(1), 129–151. https://doi.org/10.1007/s10763-017-9852-0

Utesov, A. B., & Bazarkhanova, A. A. (2022). Optimal Computing Units in the Problem of Discretizing Solutions of the Klein–Gordon Equation and Their Limit Errors. *Differential Equations*, *58*(5), 698–711. https://doi.org/10.1134/S0012266122050093

van den Eynde, S., Goedhart, M., Deprez, J., & De Cock, M. (2023). Role of Graphs in Blending Physical and Mathematical Meaning of Partial Derivatives in the Context of the Heat Equation. *International Journal of Science and Mathematics Education*, *21*(1), 25–47. https://doi.org/10.1007/s10763-021-10237-3

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering Scientific Literacy and Critical Thinking in Elementary Science Education. *International Journal of Science and Mathematics Education*, *14*(4), 659–680. https://doi.org/10.1007/s10763-014-9605-2

Vignal, M., & Wilcox, B. R. (2022). Investigating unprompted and prompted diagrams generated by physics majors during problem solving. *Physical Review Physics Education Research*, *18*(1), 10104. https://doi.org/10.1103/PhysRevPhysEducRes.18.010104

Walsh, C., Quinn, K. N., Wieman, C., & Holmes, N. G. (2019). Quantifying critical thinking: Development and validation of the physics lab inventory of critical thinking. *Physical Review Physics Education Research*, *15*(1), 10135. https://doi.org/10.1103/PhysRevPhysEducRes.15.010135

Walsh, L. N., Howard, R. G., & Bowe, B. (2007). Phenomenographic study of students' problem solving approaches in physics. *Physical Review Special Topics - Physics Education Research*, *3*(2), 1–12.

Wang, C., Shen, J., & Chao, J. (2022). Integrating Computational Thinking in STEM Education: A Literature Review. *International Journal of Science and Mathematics Education*, *20*(8), 1949–1972. https://doi.org/10.1007/s10763-021-10227-5

Weaver, J. P., Chastain, R. J., DeCaro, D. A., & DeCaro, M. S. (2018). Reverse the routine: Problem solving before instruction improves conceptual knowledge in undergraduate physics. *Contemporary Educational Psychology*, *52*, 36–47. https://doi.org/10.1016/j.cedpsych.2017.12.003

Wilcox, B. R., & Pollock, S. J. (2015). Upper-division student difficulties with separation of variables. *Physical Review Special Topics - Physics Education Research*, *11*(2), 1–13.

Wilhelm, J., Thacker, B., & Wilhelm, R. (2007). Creating Constructivist Physics for Introductory University Classes. *Electronic Journal of Science Education*, *11*(2).

Williams, M. (2018). The Missing Curriculum in Physics Problem-Solving Education. *Science & Education*. https://doi.org/10.1007/s11191-018-9970-2 Article

Xin, P. Y. (2012). *Conceptual Model-Based Problem Solving* (2nd ed.). Sense Publisher.

Yacoubian, H. A. (2015). A Framework for Guiding Future Citizens to Think Critically About Nature of Science and Socioscientific Issues. *Canadian Journal of Science, Mathematics and Technology Education*, *15*(3), 248–260. https://doi.org/10.1080/14926156.2015.1051671

Yarman, Y., Fauzan, A., Armiati, A., & Lufri, L. (2020). Analysis of Student Errors in Solving Ordinary Differential Equations Based on SOLO Taxonomy. *Journal of Physics: Conference Series*, *1554*(1), 1–7. https://doi.org/10.1088/1742-6596/1554/1/012065

Yasuda, J. I., Mae, N., Hull, M. M., & Taniguchi, M. A. (2021). Optimizing the length of computerized adaptive testing for the Force Concept Inventory. *Physical Review Physics Education Research*, *17*(1), 10115. https://doi.org/10.1103/PhysRevPhysEducRes.17.010115

Yim, J., & Lee, H. S. (2022). Students' Use of Prior Conceptions of Symbols in Finding an Equation for a Horizontal Translation of the Graph of a Function. *International Journal of Science and Mathematics Education*, *20*(8), 1699–1717. https://doi.org/10.1007/s10763-021-10230-w

Yore, L. D., & Tang, K.-S. (2022). Foundations, Insights, and Future Considerations of Reading in Science and Mathematics Education. *International Journal of Science and Mathematics Education*, *20*(1), 237–260. https://doi.org/10.1007/s10763-022-10321-2

Young, N. T., Allen, G., Aiken, J. M., Henderson, R., & Caballero, M. D. (2019). Identifying features predictive of faculty integrating computation into physics courses. *Physical Review Physics Education Research*, *15*(1), 10114. https://doi.org/10.1103/PhysRevPhysEducRes.15.010114

Yu, K.-C., Wu, P.-H., & Fan, S.-C. (2020). Structural Relationships among High School Students' Scientific Knowledge, Critical Thinking, Engineering Design Process, and Design Product. *International Journal of Science and Mathematics Education*, *18*(6), 1001–1022. https://doi.org/10.1007/s10763-019-10007-2

Yu, K. C., Fan, S. C., & Lin, K. Y. (2015). Enhancing Students' Problem-Solving Skills Through Context-Based Learning. *International Journal of Science and Mathematics Education*, *13*(6), 1377–1401. https://doi.org/10.1007/s10763-014-9567-4

Yuliati, L., Parno, P., Hapsari, A. A., Nurhidayah, F., & Halim, L. (2018). Building Scientific Literacy and Physics Problem Solving Skills through Inquiry-Based Learning for STEM Education. *Journal of Physics: Conference Series*, *1108*(1). https://doi.org/10.1088/1742-6596/1108/1/012026

Zhang, L., Wang, J., Liu, X., & Zhou, Y. (2017). A wavelet integral collocation method for nonlinear boundary value problems in physics. *Computer Physics Communications*, *215*, 91–102. https://doi.org/10.1016/j.cpc.2017.02.017