PERKULIAHAN KIMIA ORGANIK BERBANTUAN KIMIA KOMPUTASI DENGAN MODEL RADEC UNTUK MENINGKATKAN PENGUASAAN KONSEP DAN TEKNOLOGI MAHASISWA

DISERTASI

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas perkuliahan kimia organik berbantuan kimia komputasi dengan Model RADEC dalam meningkatkan penguasaan konsep dan teknologi mahasiswa. Intervensi perkuliahan diberikan kepada subyek penelitian yang telah terbentuk tanpa proses pengacakan, kemudian diukur dampaknya. Subyek penelitian terdiri atas 48 mahasiswa tahun akademik 2024/2025 pada perguruan tinggi negeri di Bandung dan Banjarmasin. Pengolahan data penelitian menggunakan metode campuran dengan desain *embedded.* Pengumpulan data menggunakan tes, dokumentasi, observasi, dan survei. Data yang terkumpul dianalisis menggunakan analisis deskriptif dan tematik, uji beda, n-gain, teknik stacking dan racking, serta uji korelasi. Hasil penelitian menunjukkan bahwa perkuliahan memiliki 4 karakteristik, yaitu menggunakan visualisasi dan data energi dari Avogadro dan ORCA; menghadirkan ide-ide baru untuk analisis kestabilan; memfasilitasi pencarian visualisasi dan data energi; serta mendukung pembelajaran mandiri, kolaboratif, dan berulang. Penerapan perkuliahan cukup efektif dan signifikan meningkatkan penguasaan konsep dan teknologi dengan n-gain yang diperoleh berada pada kategori sedang. Selanjutnya, terdapat korelasi positif yang cukup kuat dan signifikan antara kemampuan penguasaan konsep dan teknologi mahasiswa. Setiap tahap perkuliahan pada Model RADEC berkontribusi terhadap peningkatan penguasaan konsep dan teknologi mahasiswa. Pusat perkuliahan berubah dari pengajar ke mahasiswa yang ditunjukkan dengan n-gain terbesar untuk dua topik awal pada tahap *Explain* dan untuk topik ketiga pada tahap *Discuss*.

Kata Kunci: kimia komputasi, Model RADEC, penguasaan konsep, penguasaan teknologi, perkuliahan kimia organik

ABSTRACT

This study aims to analyze the effectiveness of organic chemistry course assisted by computational chemistry and RADEC Model in enhancing students' conceptual and technological understanding. The intervention was administered to an existing group of research participants without randomization and its impact was then measured. The research participants consisted of 48 students in the 2024/2025 academic year at public universities in Bandung and Banjarmasin. The study employed a mixed-methods approach with embedded design. Data were gathered through test, observation, surveys, documentations, and analyzed using descriptive and thematic analysis, different test, normalized gain, stacking and racking techniques, correlation analysis. The characteristics of the course are (1) using visualization and molecular energy data from Avogadro and ORCA, (2) facilitating the creation of new ideas to analyze the stability of compounds, (3) providing access to the process of exploration of visualizations and energy data, and (4) facilitating independent, collaborative, and iterative learning. The results indicated that the course was quite effective and led to a significant improvement in students' conceptual and technological understanding, with the obtained n-gain categorized as moderate. Furthermore, a positive correlation between conceptual and technological understanding was observed. Every stage of RADEC model contributed to enhance students' conceptual and technological understanding. The learning process gradually shifted from teacher-centered to student-centered learning, with the most notable improvements in the Explain stage for both introduction to bifunctional and diene topics and in the Discuss stage for the dicarbonyl topic.

Keywords**:** computational chemistry, conceptual understanding, organic chemistry course, RADEC Model, technological understanding.

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DAFTAR PUSTAKA

Agustin, A., Supardi, & Sunarto, W. (2018). Pengaruh penggunaan peta konsep berbasis multilevel terhadap pemahaman konsep kimia siswa. *Chemistry in Education*, 7(2).

Akçayır, G., & Akçayır, M. (2018). The flipped classroom: A review of its advantages and challenges. *Computers & Education*, 126, 334–345. https://doi.org/10.1016/j.compedu.2018.07.021

Akinyemi, O. S., & Mavhunga, E. (2021). Linking pre-service teachers' enacted topic specific pedagogical content knowledge to learner achievement in organic chemistry. *Chemistry Education Research and Practice*, 22(2), 282–302. https://doi.org/10.1039/d0rp00285b

Al-Moameri, H. H., Jaf, L. A., & Suppes, G. J. (2018). Simulation approach to learning polymer science. *Journal of Chemical Education*, 95(9), 1554–1561. https://doi.org/10.1021/acs.jchemed.8b00236

Amaral, K. E., Shank, J. D., Shibley, I. A., & Shibley, L. R. (2013). Web-enhanced general chemistry increases student completion rates, success, and satisfaction. *Journal of Chemical Education*, 90(3), 296–302. https://doi.org/10.1021/ed200580q

Anderson, L. W., & Krathwohl, D. R. (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Addison Wesley Longman, Inc.

Angeli, C., Valanides, N., & Christodoulou, A. (2016). Theoretical Considerations of Technological Pedagogical Content Knowledge. In M. C. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators*. Routledge.

Antle, J. P., *et al*. (2023). Applying density functional theory to common organic mechanisms: A computational exercise. *Journal of Chemical Education*, 100(1), 355–360. https://doi.org/10.1021/acs.jchemed.2c00935

Anwar, Y. A. S., Senam, S., & Laksono, E. W. (2018). The use of orientation/decision/do/*Discuss*/reflect (OD3R) method to increase critical thinking skill and practical skill in biochemistry learning. *Biochemistry and Molecular Biology Education*, 46(2), 107–113. https://doi.org/10.1002/bmb.21096

Archambault, L. (2016). Exploring the Use of Qualitative Methods to Examine TPACK. In M. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators*. Routledge.

Arneson, J. B., & Offerdahl, E. G. (2018). Visual literacy in bloom: Using bloom's taxonomy to support visual learning skills. *CBE Life Sciences Education*, 17(1). https://doi.org/10.1187/cbe.17-08-0178

Asmussen, G., Rodemer, M., & Bernholt, S. (2023). Blooming student difficulties in dealing with organic reaction mechanisms - an attempt at systemization. *Chemistry Education Research and Practice*, 24(3), 1035–1054. https://doi.org/10.1039/d2rp00204c

Ausubel, D. P. (1978). *Educational psychology: A cognitive view*. Holt, Rinehart & Winston.

Bakhoda, I., & Shabani, K. (2016). Response latency as a tool to study L2 Learners' ZPD, ZAD, and ongoing information processing. *Asian-Pacific Journal of Second and Foreign Language Education*, 1(1), 1–16. https://doi.org/10.1186/s40862-016-0009-4

Bond, T. G., & Fox, C. M. (2015). *Applying Rasch Model: Fundamental Measurement in Human Sciences*. Routledge.

Borg, W. R. (1963). *Educational Research: An Introduction*. Longman.

Braun, I., Langner, A., & Graulich, N. (2022). Let's draw molecules: Students' sequential drawing processes of resonance structures in organic chemistry. *Frontiers in Education*, 7, 1–24. https://doi.org/10.3389/feduc.2022.105580

Brod, G. (2021). Toward an understanding of when prior knowledge helps or hinders learning. *Science of Learning*, 6(1), 2–4. https://doi.org/10.1038/s41539-021-00103-w

Bruner, J. S. (1974). *Toward a Theory of Instruction*. Harvard University Press.

Buatip, S., Chaivisuthangkura, P., & Khumwong, P. (2019). Enhancing science teaching competency among pre-service science teachers through blended-mentoring process. *International Journal of Instruction*, 12(3), 289–306. https://doi.org/10.29333/iji.2019.12318a

Bursch, M., et al. (2022). Best-practice DFT protocols for basic molecular computational chemistry. *Angewandte Chemie*, 134(42). https://doi.org/10.1002/ange.202205735

Canelas, D. A., Hill, J. L., & Novicki, A. (2017). Cooperative learning in organic chemistry increases student assessment of learning gains in key transferable skills. *Chemistry Education Research and Practice*, 18(3), 441–456. https://doi.org/10.1039/c7rp00014f

Carle, M. S., & Flynn, A. B. (2020). Essential learning outcomes for delocalization (resonance) concepts: How are they taught, practiced, and assessed in organic chemistry? *Chemistry Education Research and Practice*, 21(2), 622–637. https://doi.org/10.1039/c9rp00203k

Chai, C. S., Koh, J. H. L., & Tsai, C.C. (2016). A Review of the Quantitative Measures of Technological Pedagogical Content Knowledge (TPACK). In M. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators*. Routledge.

Chan, N. N., *et al*. (2016). Peer assisted learning in higher education: roles, perceptions and efficacy. *Pertanika Journal of Social Sciences and Humanities*, 24(4), 1811–1822.

Cheng, G.J., *et al*. (2015). Computational organic chemistry: bridging theory and experiment in establishing the mechanisms of chemical reactions. *Journal of the American Chemical Society*, 137(5), 1706–1725. https://doi.org/10.1021/ja5112749

Clapper, T. C. (2015). Cooperative-based learning and the zone of proximal development. *Simulation and Gaming*, 46(2), 148–158. https://doi.org/10.1177/1046878115569044

Clayden, J., Greeves, N., & Warren, S. (2012). *Organic Chemistry*. Oxford University Press Inc.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education*. Routledge.

Cox, S. E. (2014). *Perceptions and Influences Behind Teaching Practices: Do Teachers Teach as They were Taught*? Brigham University Press.

Cramer, J. C. (2004). *Essentials of Computational Chemistry*. John Wiley & Sons Ltd.

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approach Fifth Edition*. SAGE Publications, Inc.

Crimmins, M. T., & Midkiff, B. (2017). High structure active learning pedagogy for the teaching of organic chemistry: Assessing the impact on academic outcomes. *Journal of Chemical Education*, 94(4), 429–438. https://doi.org/10.1021/acs.jchemed.6b00663

Danipog, D. L., & Ferido, M. B. (2011). Using art-based chemistry activities to improve students' conceptual understanding in chemistry. *Journal of Chemical Education*, 88(12), 1610–1615. https://doi.org/10.1021/ed100009a

Dong, A., Jong, M. S. Y., & King, R. B. (2020). How does prior knowledge influence learning engagement? the mediating roles of cognitive load and help-seeking. *Frontiers in Psychology*, 11(October), 1–10. https://doi.org/10.3389/fpsyg.2020.591203

Dood, A. J., & Watts, F. M. (2023). Students' strategies, struggles, and successes with mechanism problem solving in organic chemistry: A scoping review of the research literature. *Journal of Chemical Education*, 100(1), 53–68. https://doi.org/10.1021/acs.jchemed.2c00572

Eitemüller, C., Trauten, F., Striewe, M., & Walpuski, M. (2023). Digitalization of multistep chemistry exercises with automated formative feedback. *Journal of Science Education and Technology*, 32(3), 453–467. https://doi.org/10.1007/s10956-023-10043-2

Esselman, B. J., & Hill, N. J. (2016). Integration of computational chemistry into the undergraduate organic chemistry laboratory curriculum. *Journal of Chemical Education*, 93(5), 932–936. https://doi.org/10.1021/acs.jchemed.5b00815

Eun, B. (2019). Adopting a stance: Bandura and Vygotsky on professional development. *Research in Education*, 105(1), 74–88. https://doi.org/10.1177/0034523718793431

Eun, B. (2020). The zone of proximal development as an overarching concept: A framework for synthesizing Vygotsky's theories. *Educational Philosophy and Theory*, 51(1), 18–30. https://doi.org/10.1080/00131857.2017.1421941

Farrell, I. K., & Hamed, K. M. (2017). Examining the relationship between Technological Pedagogical Content Knowledge (TPACK) and student achievement utilizing the florida value-added model. *Journal of Research on Technology in Education*, 49(3–4), 161–181. https://doi.org/10.1080/15391523.2017.1328992

Fatimah, F., *et al*. (2024). Enhancing students' reading comprehension skills through the RADEC Model: A focus on elementary education. Al-Ishlah: Jurnal Pendidikan, 16(2), 2427–2439. https://doi.org/10.35445/alishlah.v16i2.5224

Fessenden, R. J., & Fessenden, J. S. (1986). *Organic Chemistry*. Wadsworth, Inc.

Finkenstaedt-Quinn, S. A., *et al*. (2020). Capturing student conceptions of thermodynamics and kinetics using writing. *Chemistry Education Research and Practice*, 21(3), 922–939. https://doi.org/10.1039/c9rp00292h

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to Design and Evaluate Research in Education*. The McGraw-Hill Companies, Inc.

Frey, R. F., Cahill, M. J., & Mcdaniel, M. A. (2017). Students' Concept-building approaches: a novel predictor of success in chemistry courses. *Journal of Chemical Education*, 94(3). https://doi.org/10.1021/acs.jchemed.7b00059

Garg, N. K. (2019). How organic chemistry became one of UCLA's most popular classes. *Journal of Biological Chemistry*, 294(46), 17678–17683. https://doi.org/10.1074/jbc.AW119.008141

Gibbs, B. C. (2014). Reconfiguring bruner: Compressing the spiral curriculum. *Phi Delta Kappan*, 95(7), 41–44. https://doi.org/10.1177/003172171409500710

Graulich, N. (2025). The tip of the iceberg in organic chemistry - revisited. *Chemistry Education Research and Practice*, 26(2), 359–376. https://doi.org/10.1039/d4rp00345d

Guseva, L. G., & Solomonovich, M. (2017). Implementing the zone of proximal development: From the pedagogical experiment to the developmental education system of Leonid Zankov. *International Electronic Journal of Elementary Education*, 9(4), 775–786.

Hake, R. (1998). *Analyzing Change/Gain Scores*. Indiana University.

Haleem, A., *et al*. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, 3(2), 275–285. https://doi.org/10.1016/j.susoc.2022.05.004

Handayani, H., *et al*. (2019). RADEC: An alternative learning of higher order thinking skills (HOTs) students of elementary school on water cycle. *Journal of Physics: Conference Series*, 1351(1). https://doi.org/10.1088/1742-6596/1351/1/012074

Hanson, M. D., *et al*. (2023). A computational experiment introducing undergraduates to geometry optimizations, vibrational frequencies, and potential energy surfaces. *Journal of Chemical Education*, 100(2), 921–927. https://doi.org/10.1021/acs.jchemed.2c01129

Hanwell, M. D., *et al*. (2012). Avogadro: An advanced semantic chemical editor, visualization, and analysis platform. *Journal of Cheminformatics*, 4(17).

Harrypersad, S., & Canal, J. P. (2023). The synthesis of ruthenocene: A methodology appropriate for the inorganic undergraduate curriculum. *Journal of Chemical Education*, 100(3), 1320–1325. https://doi.org/10.1021/acs.jchemed.2c01258

Hayati, N., *et al*. (2022). Chemistry teachers' TPACK competence: Teacher perception and lesson plan analysis. *Technium Social Sciences Journal*, 34(1), 237–247.

Hernández-Ramos, J., Cáceres-Jensen, L., & Rodríguez-Becerra, J. (2023). Educational computational chemistry for in-service chemistry teachers : A data mining approach to e-learning environment redesign. *Education Sciences*, 13.

Holme, T. A. (2023). A snapshot of organic chemistry instruction and curriculum over the past 100 years. *Journal of Chemical Education*, 100(6), 2093–2095. https://doi.org/10.1021/acs.jchemed.3c00467

Horst, J. S. (2013). Context and repetition in word learning. *Frontiers in Psychology*, 4(4), 1–11. https://doi.org/10.3389/fpsyg.2013.00149

Houseknecht, J. B., & Bates, L. K. (2020). Transition to remote instruction using hybrid just-in-time teaching, collaborative learning, and specifications grading for organic chemistry 2. *Journal of Chemical Education*, 97(9), 3230–3234. https://doi.org/10.1021/acs.jchemed.0c00749

Hrubeš, J., *et al*. (2024). Integrating computational chemistry into secondary school lessons. *Journal of Chemical Education*, 101(6), 2343–2353. https://doi.org/10.1021/acs.jchemed.3c00908

Huang, Y., & Huang, J. X. (2024). Exploring ChatGPT for next-generation information retrieval: Opportunities and challenges. *Web Intelligence*, 22(1), 31–44. https://doi.org/10.3233/WEB-230363

Infante, P., & Poehner, M. E. (2019). Realizing the ZPD in second language education: The complementary contributions of dynamic assessment and mediated development. *Language and Sociocultural Theory*, 6, 63–91. https://doi.org/10.1558/lst.38916

Jeongho, C., Su-Yin, K., & Wai, C. P. (2017). Uncritical inference test in developing basic knowledge and understanding in the learning of organic spectroscopy. *Pertanika Journal of Social Sciences and Humanities*, 25(4), 1789–1802.

Kadarohman, A., Astuti, R. M., & Khumaisah, L. M. (2020). *Kinetika dan Mekanisme Reaksi Kompleks Senyawa Organik*. UPI Press.

Kadtsyna, A. S., Chubarov, A. S., & Kadtsyn, E. D. (2022). Basic cheminformatics course for first-year chemistry students. *Journal of Chemical Education*, 99(8), 2932–2942. https://doi.org/10.1021/acs.jchemed.2c00175

Karimi-Aghdam, S. (2017). Zone of proximal development (ZPD) as an emergent system: A dynamic systems theory perspective. *Integrative Psychological and Behavioral Science*, 51(1), 76–93. https://doi.org/10.1007/s12124-016-9359-1

Ketonen, L., Nieminen, P., & Hähkiöniemi, M. (2020). The development of secondary students' feedback literacy: Peer assessment as an intervention. *Journal of Educational Research*, 113(6), 407–417. https://doi.org/10.1080/00220671.2020.1835794

Kirk, R. E. (1999). *Statistics: An Introduction*. Harcourt Brace.

Koehler, M. J., *et al*. (2014). The Technological Pedagogical Content Knowledge Framework. In *Handbook of Research on Educational Communications and Technology*. https://doi.org/10.1007/978-1-4614-3185-5

Kolb, A. Y., & Kolb, D. A. (2017). Experiential learning theory as a guide for experiential educators in higher education. *Experiential Learning & Teaching in Higher Education*, 1(1), 7–44.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall Press.

Kowalski, E. M., Koleci, C., & McDonald, K. J. (2024). Changing levels of Bloom's taxonomy in learning objectives and exam questions in first-semester introductory chemistry before and during adoption of guided Inquiry. *Education Sciences*, 14(9). https://doi.org/10.3390/educsci14090943

Kuroki, N., Mochizuki, Y., & Mori, H. (2023). Practical computational chemistry course for a comprehensive understanding of organic, inorganic, and physical chemistry: From molecular interactions to chemical reactions. *Journal of Chemical Education*, 100(2), 647–654. https://doi.org/10.1021/acs.jchemed.2c00837

Laine, P. L., *et al*. (2012). Kinetics of elementary steps in the reactions of atomic bromine with isoprene and 1,3-butadiene under atmospheric conditions. *Journal of Physical Chemistry A*, 116(24), 6341–6357. https://doi.org/10.1021/jp212127v

Laliyo, L. A. R. (2021). *Mendiagnosis Sifat Perubahan Konseptual Siswa: Penerapan Teknik Analisis* Stacking *dan* Racking *Rasch Model*. Deepublish.

Lapitan, L. D. S., *et al*. (2023). Design, implementation, and evaluation of an online flipped classroom with collaborative learning model in an undergraduate chemical engineering course. *Education for Chemical Engineers*, 43(April), 58–72. https://doi.org/10.1016/j.ece.2023.01.007

Larmer, J., & Mergendoller, J. R. (2010). Seven essentials for project-based learning. educational leadership, 68(1), 34–37.

Laswadi, L., *et al*. (2021). Developing conceptual understanding and procedural fluency for junior high school students through model-facilitated learning (MFL). *European Journal of Science and Mathematics Education*, 4(1), 67–74. https://doi.org/10.30935/scimath/9454

Lestari, H., *et al*. (2021). The impact of online mentoring in implementing RADEC learning to the elementary school teachers' competence in training students' critical thinking skills: A case study during covid-19 pandemic. *Jurnal Pendidikan IPA Indonesia*, 10(3), 346–356. https://doi.org/10.15294/JPII.V10I3.28655

Lestari, *et al*. (2021). Infusion of environment dimension of ESD into science learning through the RADEC Learning model in elementary schools. *Jurnal Penelitian Pendidikan IPA*, 7, 205–212. https://doi.org/10.29303/jppipa.v7ispecialissue.817

Lestari, *et al*. (2022). The impact of the RADEC learning model oriented ESD on students ' sustainability consciousness in elementary school. Pegem *Journal* *of Education and Instruction*, 12(2), 113–122. https://doi.org/10.47750/pegegog.12.02.11

Lieber, L., & Graulich, N. (2020). Thinking in alternatives: A task design for challenging students' problem-solving approaches in organic chemistry. *Journal of Chemical Education*, 97(10), 3731–3738. https://doi.org/10.1021/acs.jchemed.0c00248

Lieber, L. S., Graulich, N., Licini, G., & Orian, L. (2025). Exploring the Synergy of Cognitive Dissonance and Computational Chemistry: A Task design for supporting learning in organic chemistry. *Journal of Chemical Education*, 102(3), 1129–1137. https://doi.org/10.1021/acs.jchemed.4c01483

Lopez, E., *et al*. (2011). Validating the use of concept-mapping as a diagnostic assessment tool in organic chemistry: Implications for teaching. *Chemistry Education Research and Practice*, 12(2), 133–141. https://doi.org/10.1039/c1rp90018h

Lui, A. (2012). Teaching in the Zone: An Introduction to working within the zone of proximal development (ZPD). *Children's Progress.*

Lukas, S., *et al*. (2019). Improving students' TPACK through learning labs: Implementation of ichemlab and steam makerspace. *Edulearn Proceedings*, 1, 6718–6726. https://doi.org/10.21125/edulearn.2019.1611

Lynn, M. R. (1986). Determination and quantification of content validity. *Nursing Research*, 35(6).

Ma'ruf, A. S., *et al*. (2020). Colloidal learning design using RADEC Model with STEM approach based google classroom to develop student creativity. *Journal of Educational Sciences*, 4(4).

Maltagliati, A. J., *et al*. (2023). Development and evaluation of a pre-clerkship spiral curriculum: data from three medical school classes. *Medical Education Online*, 28(1). https://doi.org/10.1080/10872981.2023.2167258

Marchak, D., Shvarts-Serebro, I., & Blonder, R. (2021). Teaching chemistry by a creative approach: Adapting a teachers' course for active remote learning. *Journal of Chemical Education*, 98(9), 2809–2819. https://doi.org/10.1021/acs.jchemed.0c01341

Mardirossian, N., & Head-Gordon, M. (2017). Thirty years of density functional theory in computational chemistry: An overview and extensive assessment of 200 density functionals. *Molecular Physics*, 115(19), 2315–2372. https://doi.org/10.1080/00268976.2017.1333644

Margolis, A. A. (2020). Zone of proximal development, scaffolding and teaching practice. *Cultural-Historical Psychology*, 16(3), 15–26. https://doi.org/10.17759/chp.2020160303

Maspiroh, I., *et al*. (2025). Improving digital literacy of elementary teacher candidates through digital-based RADEC learning model. *European Journal of STEM Education*, 10(1), 1–9. https://doi.org/10.20897/ejsteme/16530

Mayer, R. E. (2005). *Cognitive theory of multimedia learning.* In Cambridge handbook of multimedia learning. Cambridge University Press.

Metz, I. K., Bennett, J. W., & Mason, S. E. (2021). Examining the Aufbau principle and ionization energies: A computational chemistry exercise for the introductory level. *Journal of Chemical Education*, 98(12), 4017–4025. https://doi.org/10.1021/acs.jchemed.1c00700

Mooring, S. R., Mitchell, C. E., & Burrows, N. L. (2016). Evaluation of a flipped, large-enrollment organic chemistry course on student attitude and achievement. *Journal of Chemical Education*, 93(12), 1972–1983. https://doi.org/10.1021/acs.jchemed.6b00367

Monteiro, N. K. V, & Firme, C. L. (2015). Teaching thermodynamic, geometric and electronic aspects of Diels-alder cycloadditions by using computational chemistry-an undergraduate experiment. *World Journal of Chemical Education*, 3(6), 141–149. https://doi.org/10.12691/wjce-3-6-3

Montgomery, C. D. (2013). A Mechanistic study of the migratory insertion reaction: A computational chemistry exercise. *Journal of Chemical Education*, 90(10), 1396–1400. https://doi.org/10.1021/ed300526k

Morris, T. H. (2020). Experiential learning – a systematic review and revision of Kolb's model. I*nteractive Learning Environments*, 28(8).

Motameni, R. (2018). The combined impact of the flipped classroom, collaborative learning, on students' learning of key marketing concepts. *Journal of University Teaching and Learning Practice*, 15(3), 1–20. https://doi.org/10.53761/1.15.3.4

Muhaimin, M., *et al*. (2019). A sequential explanatory investigation of TPACK: Indonesian science teachers' survey and perspective. *Journal of Technology and Science Education*, 9(3), 269–281.

Munir, M. T., *et al*. (2018). Flipped classroom with cooperative learning as a cornerstone. *Education for Chemical Engineers*, 23, 25–33. https://doi.org/https://doi.org/10.1016/j.ece.2018.05.001

Noguera, I., Guerrero-Roldán, A. E., & Masó, R. (2018). Collaborative agile learning in online environments: Strategies for improving team regulation and project management. *Computers and Education*, 116, 110–129. https://doi.org/10.1016/j.compedu.2017.09.008

Nugraha, T., & Prabawanto, S. (2021). The enhancement of students' mathematical conceptual understanding through RADEC learning model. *Eduma : Mathematics Education Learning and Teaching*, 10(2), 167. https://doi.org/10.24235/eduma.v10i2.9073

Nugraheni, A. R. E., & Srisawasdi, N. (2025). Development of pre-service chemistry teachers' knowledge of technological integration in inquiry-based learning to promote chemistry core competencies. *Chemistry Education Research and Practice*, 26(2), 398–419. https://doi.org/10.1039/D4RP00160E

Nurhayati, Y., *et al*. (2022). Pre-learning questions of energy sources on radec learning model: Validation and development. J*ournal of Engineering Science and Technology*, 17(2), 1028–1035.

O'Brien, M. (2016). Creating 3-dimensional molecular models to help students visualize stereoselective reaction pathways. *Journal of Chemical Education*, 93(9), 1663–1666. https://doi.org/10.1021/acs.jchemed.6b00250

O'Dwyer, A. & Childs, P. E. (2017). Who says organic chemistry is difficult? Exploring perspectives and perceptions. *Eurasia Journal of Mathematics*, *Science and Technology Education*, 13(7), 3599–3620. https://doi.org/10.12973/eurasia.2017.00748a

Oliveira, B. R. M., *et al*. (2019). Jigsaw: Using cooperative learning in teaching organic functions. *Journal of Chemical Education*, 96(7), 1515–1518. https://doi.org/10.1021/acs.jchemed.8b00765

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Psychology*, 49(6), 345–375.

Pedaste, M., Mitt, G., & Jürivete, T. (2020). What is the effect of using mobile augmented reality in K12 inquiry-based learning? *Education Sciences*, 10(4). https://doi.org/10.3390/educsci10040094

Pelter, M. W., *et al*. (2023). Computational investigation of isotopic labeling: A pandemic inspired activity. *Journal of Chemical Education*, 100(9), 3677–3682. https://doi.org/10.1021/acs.jchemed.3c00115

Phankingthongkum, S., & Limpanuparb, T. (2021). A virtual alternative to molecular model sets: a beginners' guide to constructing and visualizing molecules in open-source molecular graphics software. *BMC Research Notes*, 14(1), 1–7. https://doi.org/10.1186/s13104-021-05461-7

Polit, D. F., Beck, C. T., & Owen, S. V. (2007). Is the CVI an acceptable indicator of content validity? Appraisal and Recommendations. *Research in Nursing & Health*, 30, 459–467. https://doi.org/10.1002/nur

Pölloth, B. (2025). High school students experimenting with computational chemistry: design-based research on and through the "comp-chem-lab." *Journal of Chemical Education*, 102(4), 1367–1379. https://doi.org/10.1021/acs.jchemed.4c01136

Pölloth, B., Schwarzer, S., & Zipse, H. (2020). Student individuality impacts use and benefits of an online video library for the organic chemistry laboratory. *Journal of Chemical Education*, 97(2), 328–337. https://doi.org/10.1021/acs.jchemed.9b00647

Ponmani, M., & Geetha, R. (2022). integration of zone of proximal development (ZPD) and ICTs in language learning. In *Contemporary ELT Strategies in Engineering Pedagogy*. Routledge.

Pratama, Y. A., Sopandi, W., & Hidayah, Y. (2019). RADEC learning model: The importance of building critical thinking skills in Indonesian context. *International Journal for Educational and Vocational Studies*, 1(2), 109–115. https://doi.org/10.29103/ijevs.v1i2.1379

Riza, L. S., *et al*. (2023). Educational technology using multimedia in science learning : A systematic review. *Bulletin of Social Informatics Theory and Application*, 7(2), 163–181.

Rodriguez-Becerra, J., *et al*. (2019). Novel educational computational chemistry learning environments effect on preservice chemistry teachers' perceptions of technological pedagogical content knowledge. P*roceedings of the The 2019 ESERA Conference*, 26–30.

Rodríguez-Becerra, J., *et al*. (2020). Developing technological pedagogical science knowledge through educational computational chemistry: A case study of pre-service chemistry teachers' perceptions. *Chemistry Education Research and Practice*, 21(2), 638–654. https://doi.org/10.1039/c9rp00273a

Rohmawatiningsih, W., Rachman, I., & Yayoi, K. (2021). The implementation of RADEC learning model in thematic learning to increase the concept understanding of electrical phenomenon. *Momentum: Physics Education Journal*, 5(2), 121–131. https://doi.org/10.21067/mpej.v5i2.5412

Sadarangani, I. R., Serafin, J., & Chabra, J. (2024). Student perceptions of meaningful learning in online and hybrid (hands-on/online) laboratories at a large urban university in general and organic chemistry. *Journal of Chemical Education*, 101(4), 1480–1488. https://doi.org/10.1021/acs.jchemed.3c00541

Sarayreh, R. (2021). The Effect of problem-based learning strategy on developing critical thinking skills. *Elementary Education Online*, 20(2), 89–95. https://doi.org/10.17051/ilkonline.2021.02.03

Sastrohamidjojo, H. (2018). Kimia Dasar. UGM Press.

Sayle, R. A. (2015). So you think you understand tautomerism? *Journal of Computer-Aided Molecular Design*, 24(6–7), 485–496. https://doi.org/10.1007/s10822-010-9329-5

Scherer, R., *et al*. (2021). Profiling teachers' *Read*iness for online teaching and learning in higher education: Who's *Read*y? *Computers in Human Behavior*, 118. https://doi.org/10.1016/j.chb.2020.106675

Schwedler, S. & Kaldewey, M. (2020). Linking the submicroscopic and symbolic level in physical chemistry: How voluntary simulation-based learning activities foster first-year university students' conceptual understanding. *Chemistry Education Research and Practice*, 21(4), 1132–1147. https://doi.org/10.1039/c9rp00211a

Senol, S. (2021). ChemistDice: A game for organic functional groups. *Journal of Chemical Education*, 98(2), 535–539. https://doi.org/10.1021/acs.jchemed.0c01163

Setiawan, D., Sopandi, W., & Hartati, T. (2019). Kemampuan menulis teks eksplanasi dan penguasaan konsep siswa sekolah dasar melalui implementasi model pembelajaran RADEC. *Premiere Educandum : Jurnal Pendidikan Dasar dan Pembelajaran*, 9(2), 130. https://doi.org/10.25273/pe.v9i2.4922

Setyarini, M., *et al*. (2022). In-house training of 3D molecular modeling using avogradro for high school chemistry teachers. *Journal of Social Research and Community Service*, 1(1), 15–22.

Shaw, J. L. (2023). Promoting meaningful learning through incorporation of creative exercises in inorganic chemistry. *Journal of Chemical Education*, 100(1), 69–79. https://doi.org/10.1021/acs.jchemed.2c00598

Shemy, N. S. (2022). Digital infographics design (static vs dynamic): its effects on developing thinking and cognitive load reduction. *International Journal of Learning, Teaching and Educational Research*, 21(5), 104–125. https://doi.org/10.26803/ijlter.21.5.6

Shopova, T. (2014). Digital literacy of students and its improvement at the university. *Journal on Efficiency and Responsibility in Education and Science*, 7(2), 26–32. https://doi.org/10.7160/eriesj.2014.070201

Siregar, L. S., Wahyu, W., & Sopandi, W. (2020). Polymer learning design using *Read*, *Answer*, *Discuss*, *Explain* and *Create* (RADEC) model based on Google Classroom to develop student's mastery of concepts. *Journal of Physics: Conference Series*, 1469(1). https://doi.org/10.1088/1742-6596/1469/1/012078

Smagorinsky, P. (2018). Deconflating the ZPD and instructional scaffolding: Retranslating and reconceiving the zone of proximal development as the zone of next development. *Learning, Culture and Social Interaction*, 16, 70–75. https://doi.org/10.1016/j.lcsi.2017.10.009

Snyder, H. D. & Kucukkal, T. G. (2021). Computational chemistry activities with Avogadro and ORCA. *Journal of Chemical Education*, 98(4), 1335–1341. https://doi.org/10.1021/acs.jchemed.0c00959

Solomon, T. W. G., & Fryhle, C. B. (2011). *Organic Chemistry*. John Wiley & Sons, Inc.

Sopandi, W. (2017). The quality improvement of learning processes and achievements through the *Read-Answer-Discuss-Explain*-and-*Create* learning model implementation. *Proceeding 8th Pedagogy International Seminar 2017: Enhancement of Pedagogy in Cultural Diversity Toward Excellence in Education*, 8, 132–139.

Sopandi, W., *et al*. (2021). *Model Pembelajaran RADEC: Teori dan Implementasi di Sekolah*. UPI Press.

Soyemi, A. & Szilvási, T. (2021). Trends in computational molecular catalyst design. *Dalton Transactions,* 50(30), 325–339. https://doi.org/10.1039/D1DT01754C

Sozbilir, M., Pinarbaşi, T., & Canpolat, N. (2017). Prospective chemistry teachers' conceptions of chemical thermodynamics and kinetics. *Eurasia Journal of Mathematics, Science and Technology Education*, 6(2), 111–121. https://doi.org/10.12973/ejmste/75232

Spector, J. M., *et al*. (2014). *Handbook of Research on Educational Communications and Technology: Fourth Edition*, 1–1005. https://doi.org/10.1007/978-1-4614-3185-5

Suárez-Rodríguez, J., *et al*. (2018). A basic model of integration of ICT by teachers: competence and use. *Educational Technology Research and Development*, 66(5), 1165–1187. https://doi.org/10.1007/s11423-018-9591-0

Sujana, A., *et al*. (2021). Fundamental concepts and chemical representations on sea pollutant migration: can it be improved through RADEC. Moroccan *Journal of Chemistry,* 9(2), 328–338. https://doi.org/10.48317/IMIST.PRSM/morjchem-v9i2.27585

Sukardi, R. R., Sopandi, W., & Riandi, R. (2021). Repackaging RADEC learning model into the online mode in science class. *Journal of Physics: Conference Series*, 1806(1). https://doi.org/10.1088/1742-6596/1806/1/012142

Sumintono, B., & Widhiarso, W. (2015). *Aplikasi Pemodelan Rasch pada Asesmen Pendidikan*. Trim Komunikata.

Sweller, J. (1999). *Instructional Design in Technical Areas*. Australian Council for Educational Research Press.

Taber, K. S. (2013). A common core to chemical conceptions: learners' conceptions of chemical stability, change and bonding. C*oncepts of Matter in Science Education*, 13, 391–418. https://doi.org/10.1007/978-94-007-5914-5_19

Takaya, K. (2008). Jerome Bruner's theory of education: From early Bruner to later Bruner. I*nterchange*, 39(1), 1–19.

Tannenbaum, R. J. & Katz, I. R. (2008). Setting standards on the core and advanced iSkills assessments. *Educational Testing Service*, 5(1).

Tavares, M. C., Azevedo, G., & Marques, R. P. (2022). The challenges and opportunities of era 5.0 for a more humanistic and sustainable society—a literature review. *Societies*, 12(6), 1–21. https://doi.org/10.3390/soc12060149

Thompson, K., *et al*. (2021). Trends in education technology in higher education. *Australasian Journal of Educational Technology*, 37(3), 1–4. https://doi.org/10.14742/ajet.7396

Tirado-Rives, J. & Jorgensen, W. L. (2008). Performance of B3LYP density functional methods for a large set of organic molecules. *Journal of Chemical Theory and Computation*, 4(2), 297–306. https://doi.org/10.1021/ct700248k

Traube, T. & Blonder, R. (2023). A computational chemistry course for teachers: From research laboratories to high-school chemistry teaching. *Journal of Chemical Education*, 100(11), 4360–4368. https://doi.org/10.1021/acs.jchemed.3c00645

Tristán-López, A. & Ylizaliturri-Salcedo, M. A. (2014). Evaluation of ICT competencies. In *Handbook of Research on Educational Communications and Technology*. Springer.

Tsamago, H. & Bayaga, A. (2023). Self-organized learning environments (SOLEs) pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM: The South African study. *European Journal of Science and Mathematics Education*, 11(3), 533–555. https://doi.org/10.30935/scimath/13038

Uyulgan, M. A. & Akkuzu, N. (2018). Educational short videos to utilize in the biochemistry laboratory: Opinions of university students. *Journal of Baltic Science Education*, 17(3), 496–510. https://doi.org/10.33225/jbse/18.17.496

Valtonen, T., *et al*. (2018). Differences in pre-service teachers' knowledge and *Read*iness to use ICT in education. *Journal of Computer Assisted Learning*, 34(2), 174–182. https://doi.org/10.1111/jcal.12225

Vandenplas, J. R., *et al*. (2021). Use of simulations and screencasts to increase student understanding of energy concepts in bonding. *Journal of Chemical Education*, 98(3), 730–744. https://doi.org/10.1021/acs.jchemed.0c00470

Vygotsky, L. (1978). *Interaction between Learning and Development*. Freeman and Company.

Ward, R. (1994). *Bifunctional Compound*. Oxford University Press.

Weigend, F., Furche, F., & Ahlrichs, R. (2003). Gaussian basis sets of quadruple zeta valence quality for atoms H-Kr. *Journal of Chemical Physics*, 119(24), 12753–12762. https://doi.org/10.1063/1.1627293

Weimer, M. (2013). *Learner-centered Teaching: Five Key Changes to Practice*. John Wiley & Sons.

Welch, H., Suri, D., & Durant, E. (2009). Rubrics for assessing oral communication in the capstone design experience: Development, application, analysis and refinement. *International Journal of Engineering Education*, 25(5), 952–961.

Wikandari, R., *et al*. (2021). Combining a flipped learning approach and an animated video to improve first-year undergraduate students' understanding of electron transport chains in a biochemistry course. *Journal of Chemical Education*, 98(7), 2236–2242. https://doi.org/10.1021/acs.jchemed.0c01477

Wright, B. (2003). Rack and stack: time 1 vs. time 2 or *pretest* vs. *posttest*. *Rasch Measurement Transactions*, 17(1).

Xue, D. & Stains, M. (2020). Exploring students' understanding of resonance and its relationship to instruction. *Journal of Chemical Education*, 97(4), 894–902. https://doi.org/10.1021/acs.jchemed.0c00066

Yohana, I., Sopandi, W., & Wahyu, W. (2022). The Urgency of implementation RADEC learning model to understanding of three levels representation in chemistry. *Journal of Educational Sciences*, 6(2), 286–293.

Zhang, D. (2023). Enhancing students' understanding of the structures and aromaticities of cyclobutadiene and cyclooctatetraene through a computational chemistry exercise. *Journal of Chemical Education*, 100(9), 3717−3723. https://doi.org/10.1021/acs.jchemed.3c00376

Zhang & Tur, G. (2024). A systematic review of ChatGPT use in K-12 education. *European Journal of Education*, 59(2), 1–22. https://doi.org/10.1111/ejed.12599

Zimmerman, J. B. & Moylan, A. R. (2009). *Self-Regulation: Where Metacognition and Motivation Intersect.* In Handbook of Metacognition in Education. Routledge.

Zou, Y., *et al*. (2025). Digital learning in the 21st century: trends, challenges, and innovations in technology integration. *Frontiers in Education*, 10. https://doi.org/10.3389/feduc.2025.1562391