PEMBELAJARAN PROYEK PEMBUATAN FILTER AIR LIMBAH CUCI PIRING STEM-ESD: *CLEAN WATER AND SANITATION* TERHADAP KETERAMPILAN REKAYASA DAN AKSI SISWA

SKRIPSI

diajukan untuk memenuhi sebagai syarat memperoleh gelar sarjana pendidikan
Program Studi Pendidikan Biologi

oleh:

Lu'lu Luthfiyah

2105798

PROGRAM STUDI PENDIDIKAN BIOLOGI

FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM

UNIVERSITAS PENDIDIKAN INDONESIA

BANDUNG

2025

PEMBELAJARAN PROYEK PEMBUATAN FILTER AIR LIMBAH CUCI PIRING STEM-ESD: *CLEAN WATER AND SANITATION* TERHADAP KETERAMPILAN REKAYASA DAN AKSI SISWA

Oleh

Lu'lu Luthfiyah

Sebuah skripsi yang diajukan untuk memenuhi salah satu syarat memperoleh gelar

Sarjana Pendidikan pada Program Studi Pendidikan Biologi

Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam

Universitas Pendidikan Indonesia

2025

LEMBAR PENGESAHAN

LU'LU LUTHFIIYAH

PEMBELAJARAN PROYEK PEMBUATAN FILTER AIR LIMBAH CUCI PIRING STEM-ESD: *CLEAN WATER AND SANITATION* TERHADAP KETERAMPILAN REKAYASA DAN AKSI SISWA

NIM 2105798

Disetujui dan disahkan oleh:

Pembimbing I,

Prof. Dr. Phil. Ari Widodo, M. Ed
NIP. 196705271992031001

Pembimbing II,

Dr. Hj. Siti Sriyati, M. Si.
NIP. 196409281989012001

Mengetahui,

Ketua Program Studi Pendidikan Biologi

Dr. Kusnadi, M.Si
NIP. 196805091994031001

PERNYATAAN BEBAS PLAGIARISME

Saya yang bertanda tangan di bawah ini:

Nama : Lu'lu Luthfiyah

NIM : 2105798

Program Studi : Pendidikan Biologi

Judul Karya : Pembelajaran Proyek Pembuatan Filter Air Limbah Cuci Piring STEM-ESD: *Clean Water And Sanitation* Terhadap Keterampilan Rekayasa dan Aksi Siswa

Dengan ini menyatakan bahwa karya tulis ini merupakan hasil kerja saya sendiri. Saya menjamin bahwa seluruh isi karya ini, baik sebagian maupun keseluruhan, bukan merupakan plagiarisme dari karya orang lain, kecuali pada bagian yang telah dinyatakan dan disebutkan sumbernya dengan jelas. Jika di kemudian hari ditemukan pelanggaran terhadap etika akademik atau unsur plagiarisme, saya bersedia menerima sanksi sesuai peraturan yang berlaku di Universitas Pendidikan Indonesia.

Bandung, Agustus 2025

Lu'lu Luthfiyah

KATA PENGANTAR

Bismillahirrahmanirrahim, Alhamdulillah rabbil a'alamin, Hasbunallah Wa ni'mal Wakil kepada, segala puji kepada Allah Subhanahu wa Ta'ala atas limpahan rahmat, taufik, dan Hidayah-Nya sehingga penulis dapat menyelesaikan skripsi ini dengan baik. Penyusunan skripsi ini tidak akan terselesaikan tanpa bantuan, bimbingan, dan dukungan dari berbagai pihak. Oleh karena itu, dengan penuh rasa hormat dan syukur, penulis menyampaikan terima kasih yang sebesar-besarnya kepada:

1. Bapak Prof. Dr. Phil H. Ari Widodo, M.Ed. selaku Dosen Pembimbing satu yang penuh kesabaran telah memberikan arahan, masukan, serta motivasi bagi penulis sejak tahapan perencanaan hingga penyelesaian skripsi ini.
2. Ibu Dr. Hj. Siti Sriyati, M.Si. selaku Dosen Pembimbing dua yang dengan penuh perhatian telah membimbing, mengarahkan, serta memberikan masukan berharga selama proses penyusunan skripsi sehingga penulis dapat menyempurnakan penelitian ini dengan baik.
3. Ibu Dr. Rini Solihat, M.Si. dan Bapak Prof. Dr. H. Riandi, M.Si. selaku Dosen Pembimbing payung penelitian STEM-ESD, yang telah membantu selama proses penelitian skripsi, memberikan masukan dan saran yang membangun, serta solusi terhadap berbagai hal yang tidak terduga.
4. Bapak Dr. Kusnadi, M.Si. selaku Ketua Program Studi Pendidikan Biologi yang telah mendukung penulis agar dapat merasakan fasilitas kampus dan perkuliahn dengan baik.
5. Ibu Dr. Mimin Nurjhani Kusumastuti, M.Pd. selaku Dosen Pembimbing Akademik yang telah membimbing penulis selama empat tahun selama masa studi perkuliahan, memberikan arahan, bantuan serta motivasi sehingga penulis dapat menyelesaikan perkuliahan dengan tepat waktu dan lancar.
6. Seluruh Ibu dan Bapak Dosen Program Studi Pendidikan Biologi yang dengan tulus telah membagikan ilmu, menanamkan nilai-nilai berharga,

serta memberikan keberkahan selama proses pembelajaran, sehingga penulis dapat meraih pengetahuan yang bermakna dan bermanfaat sepanjang empat tahun menempuh pendidikan.

7. Ibu Rini Rahmayanti A.A., S.Pd. selaku Wakil Kepala sekolah bidang Kurikulum dan Bapak Yoga Mufti Wibowo S.Pd. selaku Guru pengampuh mata pelajaran Biologi Terimakasih atas kesempatan dan izin yang diberikan kepada penulis untuk melakukan uji coba instrumen penelitian di SMAN 13 Bandung.
8. Siswa-Siswi kelas XI-6 SMAN 13 Bandung tahun ajaran 2024/2025 atas kesediaan menjadi responden uji coba instrumen aksi dalam penelitian ini.
9. Bapak Rudi Suyadi S.Pd. selaku PLP Workshop FPMIPA UPI yang telah membantu serta membimbing peneliti dalam membuat prototipe filter air
10. Bapak Iqbal Issaghozi, S.P.d selaku Wakil Kepala sekolah bidang Kurikulum dan Ibu Ecin Kuraesin, S.Pd. selaku Guru pengampuh pelajaran Biologi di SMAN 19 Bandung penulis menyampaikan apresiasi dan terima kasih yang telah memberikan izin serta membimbing dan mendampingi dengan penuh kesabaran sepanjang pelaksanaan penelitian.
11. Siswa-Siswi kelas X-B dan X-C SMAN 19 Bandung tahun ajaran 2024/2025 yang telah bersedia menjadi responden dan turut aktif dalam segala rangkaian kegiatan penelitian.
12. Rekan satu tim payung penelitian STEM-ESD yaitu Ailsya, Astri, Siti, Shiva, Fitri, Nurani, Eva, Chairani, Alya, Ihat, Qisthi, Filzah serta Inggi atas segala kerja sama, bantuan, motivasi dan saling menguatkan selama proses pengerjaan skripsi.
13. Teman-Teman Kelas Rodi A 2021 yang yang telah menjadi teman seperjuangan selama empat tahun masa studi dan senantiasa mendoakan serta memberi semangat.
14. Sahabat-sahabat penulis yang senantiasa membersamai selama empat tahun di Bandung, memberikan motivasi, bantuan, serta menciptakan kenangan indah yang mewarnai masa perkuliahan yakni, Ailsya Machira Berliani,

Astri Afifah Rohana, Nasywa Putri Zahrani, Siti Nuraisyah, dan Shiva Aulia Sari dan Wardatul Jannah.

15. Teh Zia Nazaliah Ainisyifa dan Teh Lina Amalia selaku kakak tingkat yang telah memberikan arahan serta menjawab seluruh perntanyaan dan kebingunan penulis selama proses penelitian.

Sebagai penutup, ucapan terima kasih yang tak terhingga penulis sampaikan kepada Umi tercinta sebagai orang tua, sosok yang tak henti-hentinya menyelipkan nama penulis dalam setiap doa dan sujudnya. Segala pengorbanan, kasih sayang, dan dukungan yang tak ternilai selama ini menjadi alasan utama penulis mampu bertahan dan menyelesaikan perjalanan panjang ini. Semoga Allah membalas setiap lelah dan cinta yang Umi berikan dengan keberkahan yang tak berkesudahan. Ucapan terima kasih juga penulis tujukan kepada adik tercinta, yang telah memberikan motivasi dan membantu penulis selama proses penelitian berlangsung. Sehingga menjadi penguat dan penyemangat tersendiri bagi penulis dalam menyelesaikan tugas akhir ini. Tak lupa, rasa terima kasih yang paling dalam penulis haturkan kepada Abi tersayang, yang meskipun telah tiada, namun nilai-nilai kehidupan, prinsip, dan semangat yang Abi tanamkan sejak dulu menjadi cahaya dan pegangan hidup penulis hingga mampu bertahan dan menyelesaikan studi ini. Doa penulis selalu menyertaimu, Abi.

Bandung, 07 Agustus 2025

Lu’lu Luthfiyah

ABSTRAK

Krisis air bersih menjadi isu global yang dihadapi saat ini, salah satu faktor yang menjadi penghambat ketercukupan air bersih yang layak di Indonesia sering terjadi musim kemarau di sejumlah daerah. Dalam konteks pendidikan pembelajaran berbasis proyek dengan model pembelajaran STEM-ESD yang mengangkat tema *Clean Water and Sanitation*, khususnya topik *water scarcity and water use efficiency*, memberikan ruang bagi peserta didik untuk terlibat aktif dalam merancang solusi atas permasalahan nyata di lingkungan sekitar mereka. Salah satu bentuk implementasinya adalah melalui pengelolaan air limbah rumah tangga, seperti air bekas cucian piring, yang sering kali menjadi penyumbang permasalahan krisis air bersih. Berdasarkan permasalahan tersebut, tujuan dari penelitian ini untuk memperoleh informasi secara mendalam mengenai implementasi pembelajaran proyek pembuatan filter air limbah cuci piring berbasis STEM-ESD: *Clean Water and Sanitation* terhadap keterampilan rekayasa dan aksi siswa. Metode yang digunakan adalah pendekatan kuantitatif dengan *pre-eksperimental* dengan desain *one group pretest-posttest design*. Subjek penelitian adalah 63 siswa kelas X di salah satu SMA di Bandung. Hasil dari penelitian ini keterlibatan siswa dalam pembelajaran proyek pembuatan filter air limbah cuci piring berbasis STEM-ESD terkait isu *Clean Water and Sanitation* berkontribusi terhadap keterampilan rekayasa siswa yang berada pada kategori cukup dengan skor 71,2% dan menunjukkan adanya peningkatan aksi siswa terhadap isu keberlanjutan dengan score N-Gain 0,102.

Kata kunci: STEM-ESD, *Clean Water and Sanitation,* Keterampilan rekayasa, aksi siswa

ABSTRACT

The clean water crisis is a global issue currently being faced, one of the factors that hinders the sufficiency of adequate clean water in Indonesia is the frequent dry season in several regions. In the context of project-based learning education with the STEM-ESD learning model that raises the theme of Clean Water and Sanitation, specifically the topic of water scarcity and water use efficiency, provides space for students to be actively involved in designing solutions to real problems in their environment. One form of implementation is through the management of household wastewater, such as used dishwashing water, which often contributes to the clean water crisis problem. Based on these problems, the purpose of this study is to obtain in-depth information regarding the implementation of learning projects for making dishwashing wastewater filters based on STEM-ESD: Clean Water and Sanitation on engineering skills and student actions. The method used is a quantitative approach with a pre-experimental design with a one group pretest-posttest design. The research subjects were 63 grade 10 students at a high school in Bandung. The results of this study show that student involvement in learning about the STEM-ESD-based dishwashing wastewater filter making project related to Clean Water and Sanitation issues contributes to students' engineering skills which are in the sufficient category with a score of 71.2% and shows an increase in student action on sustainability issues with an N-Gain score of 0.102.

Keywords: STEM-ESD, *Clean Water and Sanitation, Engineering Skills, Student Action*

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR LAMPIRAN

DAFTAR PUSTAKA

Abidin, Z., Risma Arianti, A., & Anggriawan, Y. H. (2024). Integrating STEM and Environmental Education: Effects On Student Attitudes and Knowledge. *International Journal of Mathematics and Science Education*, *1*(1), 48–54. https://doi.org/10.62951/ijmse.v1i1.80

AlAli, R., Alsoud, K., & Athamneh, F. (2023). Towards a Sustainable Future: Evaluating the Ability of STEM-Based Teaching in Achieving Sustainable Development Goals in Learning. *Sustainability (Switzerland)*, *15*(16). https://doi.org/10.3390/su151612542

Allen, P. J., Chang, R., Gorrall, B. K., Waggenspack, L., Fukuda, E., Little, T. D., & Noam, G. G. (2019). From Quality to Outcomes: A National Study of Afterschool STEM Programming. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-019-0191-2

Almers, E. (2013). Pathways to Action Competence for Sustainability—Six Themes. *The Journal of Environmental Education*, *44*(2), 116–127. https://doi.org/10.1080/00958964.2012.719939

Andriyatno, I., Purwianingsih, W., Solihat, R., Gusti, U. A., & Yusni, D. (2024). The Eurasia Proceedings of Educational & Social Sciences (EPESS) The Eurasia Proceedings of Educational Improving Students' Collaboration Skills Through Project-Based Learning on Environmental Change Material. *& Social Sciences (EPESS)*, *34*. www.isres.org

Ayotte-Beaudet, J. P., Hasni, A., Vinuesa, V., Rodrigue-Poulin, É., Quintela Do Carmo, G., Beaudry, M. C., L'Heureux, K., & Paquette, A. (2025). Impact of outdoor place-based learning on elementary school students' ability to make unsolicited observations about living organisms over time. *Journal of Biological Education*, *59*(2), 321–339. https://doi.org/10.1080/00219266.2024.2332741

Badan Pusat Statistik Indonesia. (2023). *Statistik Indonesia Dalam Infografis (Statistical Yearbook of Indonesia in Infographics) 2023*. https://www.bps.go.id/id

Badan Standar, K. dan A. P. (2024). *Capaian Pembelajaran Kurikulum Merdeka 2024*. Kementerian Pendidikan,Kebudayaan,Riset,danTeknologi.

Bangay, C. (2016). Protecting the future: The role of school education in sustainable development – an Indian case study. *International Journal of*

Development Education and Global Learning, *8*(1). https://doi.org/10.18546/ijdegl.8.1.02

Bramwell-Lalor, S., Kelly, K., Ferguson, T., Hordatt Gentles, C., & Roofe, C. (2020). Project-based Learning for Environmental Sustainability Action. *Southern African Journal of Environmental Education*, *36*. https://doi.org/10.4314/sajee.v36i1.10

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. Nasional Science Teachers Association Press. www.nsta.org/permissions.

Campbell, N. A., Reece Berkeley, ane B., Lisa Urry, C. A., Cain, M. L., Minorsky, P. V, & fackson, R. B. (2008). *Biologi Edisi Kedelapan Jilid 3* (8th ed.). Penerbit Erlangga. http://www.erlangga.co.id

Chen, S. Y., & Liu, S. Y. (2020). Developing students' action competence for a sustainable future: A review of educational research. In *Sustainability (Switzerland)* (Vol. 12, Issue 4). MDPI. https://doi.org/10.3390/su12041374

Cheng, M.-F., Lo, Y.-H., & Cheng, C.-H. (2024). The impact of STEM curriculum on students' engineering design abilities and attitudes toward STEM. *International Journal of Technology and Design Education*, *34*(5), 1805–1833. https://doi.org/10.1007/s10798-024-09883-9

Chien, Y. H., Liu, C. Y., Chan, S. C., & Chang, Y. S. (2023). Engineering design learning for high school and college first-year students in a STEM battlebot design project. *International Journal of STEM Education*, *10*(1). https://doi.org/10.1186/s40594-023-00403-0

Creswell, J. W. (2023). *Research Design: Planning, Conducting, and Evaluating Quantitative and Qualitative Research* (6th ed.).

Cross, J. H., Chikofsky, E. J., & May, C. H. (1992). Reverse Engineering. In *Advances in Computers* (Vol. 35, Issue C, pp. 199–254). Advances in Computers. https://doi.org/10.1016/S0065-2458(08)60596-3

Damanik, F. H. S., & Saliman, S. (2023). Sustainable Education and Student Action: Understanding Student Contributions to Addressing Climate Change. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 197–210. https://doi.org/10.29303/jppipa.v9ispecialissue.6142

Darma, B. (2021). *Statistika Penelitian Menggunakan SPSS (Uji Validitas, Uji Reliabilitas, Regresi Linier Sederhana, Regresi Linier Berganda, Uji t, Uji F, R^2).* Guepedia.

Direktorat Pengendalian Pencemaran dan Kerusakan Lingkungan. (2023). *Laporan Kinerja Kementrian Lingkungan Hidup dan Kehutanan 2023 Republik Indonesia*.

Dwinandana, T. A. (2022). Peran Aktivitas Reverse Engineering pada Jurusan Teknik dan Desain di Perguruan Tinggi. *Productum: Jurnal Desain Produk (Pengetahuan Dan Perancangan Produk)*, *5*(2), 101–106. https://doi.org/https://doi.org/10.24821/productum.v5i2.7749

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, *94*(1), 103–120. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

English, L. D., & King, D. T. (2015). STEM learning through engineering design: fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, *2*(1). https://doi.org/10.1186/s40594-015-0027-7

Ergül, N. R., & Çalış, S. (2021). Examination of High School Students' Engineering Design Skills: Example of Electromagnetism*. *Journal of Turkish Science Education*, *18*(4), 765–780. https://doi.org/10.36681/tused.2021.102

Fadhilah, I. (2022). *Pengolahan Limbah Cair Rumah Makan Menjadi Air Bersih dengan Metode Kombinasi Saringan Bertingkat-Ultrafiltrasi Membran Polyethersulfone (Pes)*. Universitas Islam Negeri Ar-Raniry.

Fairhurst, N., Koul, R., & Sheffield, R. (2023). Students' perceptions of Their STEM Learning Environmen. *Learning Environments Research*, *26*(3), 977–998. https://doi.org/10.1007/s10984-023-09463-z

Fathurohman, I., Amri, M. F., Septiyanto, A., & Riandi. (2023). Integrating STEM based Education for Sustainable Development (ESD) to Promote Quality Education: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 1052–1059. https://doi.org/10.29303/jppipa.v9i11.4430

Filali, H., Barsan, N., Souguir, D., Nedeff, V., Tomozei, C., & Hachicha, M. (2022). Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review. *Sustainability*, *14*(2), 665. https://doi.org/10.3390/su14020665

Firda, R. (2021). *Pembelajaran STEM Menggunakan Konteks ESD Untuk Meningkatkan Keterampilan Berpikir Kreatif dan Sustainability Consciousness Pada Materi Pencemaran di Hutan Mangrove Surabaya*. Universitas Pendidikan Indonesia.

Firda, R.-, Kaniwati, I., & Sriyati, S. (2021). STEM Learning in Sustainability Issues to Improve Sustainability Consciousness of Junior High School Students. *PAEDAGOGIA*, *24*(1), 53. https://doi.org/10.20961/paedagogia.v24i1.54212

Firmanshah, M. I., Abdullah, N., & Fariduddin, M. N. (2023). The Relationship of School Students' Environmental Knowledge, Attitude, Behavior, and Awareness toward the Environment: A Systematic Review. *International Journal of Academic Research in Progressive Education and Development*, *12*(1). https://doi.org/10.6007/IJARPED/v12-i1/15707

Fitriyani, A. (2024). *Pengaruh Pembelajaran Proyek STEM-ESD Terkait SDGS-6 (Clean Water and Sanitation) Terhadap Kreativitas dan Aksi Siswa*. Universitas Pendidikan Indonesia.

García-Salirrosas, E. E., Escobar-Farfán, M., Gómez-Bayona, L., Moreno-López, G., Valencia-Arias, A., & Gallardo-Canales, R. (2023). Influence of environmental awareness on the willingness to pay for green products: an analysis under the application of the theory of planned behavior in the Peruvian market. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1282383

Giamellaro, M., Ewing, B., & Siegel, D. (2025). Affordances and Constraints to Implementing Project-Based STEM: A Case Study of Systemic School Change. *International Journal of Science and Mathematics Education*, *23*(3), 849–869. https://doi.org/10.1007/s10763-024-10487-x

Hadjichambis, A. C., & Paraskeva-Hadjichambi, D. (2020). Environmental citizenship questionnaire (ECQ): The development and validation of an evaluation instrument for secondary school students. *Sustainability (Switzerland)*, *12*(3). https://doi.org/10.3390/SU12030821

Hadjichambis, A. Ch., Paraskeva-Hadjichambi, D., & Georgiou, Y. (2022). Evaluating a Novel Learning Intervention Grounded in the Education for Environmental Citizenship Pedagogical Approach: A Case Study from Cyprus. *Sustainability*, *14*(3), 1398. https://doi.org/10.3390/su14031398

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Hochachka, G. (2024). When concern is not enough: Overcoming the climate awareness-action gap. *Ambio*, *53*(8), 1182–1202. https://doi.org/10.1007/s13280-024-01999-5

Höpfl, L., Grimlitza, M., Lang, I., & Wirzberger, M. (2024). Promoting sustainable behavior: addressing user clusters through targeted incentives. *Humanities and Social Sciences Communications*, *11*(1). https://doi.org/10.1057/s41599-024-03581-6

Huang, N. tang, Chang, Y. shan, & Chou, C. hui. (2020). Effects of creative thinking, psychomotor skills, and creative self-efficacy on engineering design creativity. *Thinking Skills and Creativity*, *37*. https://doi.org/10.1016/j.tsc.2020.100695

Hughes, A. J., & Denson, C. D. (2021). Scaffolding middle and high school students' engineering design experiences: Quality problem-scopeing promoting successful solutions. *Journal of Technology Education*, *32*(2), 4–20. https://doi.org/10.21061/JTE.V32I2.A.1

Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022). Action competencies for sustainability and its implications to environmental education for prospective science teachers: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(8). https://doi.org/10.29333/ejmste/12235

Isnawan, M. G. (2020). *Kuasi Eksperimen*. Nahir Al-Kutub Indonesia. https://www.researchgate.net/publication/339040496

Jensen, B. B., & Schnack, K. (1997). The action competence approach in environmental education. *Environmental Education Research*, *3*(2), 163–178. https://doi.org/10.1080/1350462970030205

Jin, S.-H., Song, K.-I., Shin, D. H., & Shin, S. (2015). A Performance-Based Evaluation Rubric for Assessing and Enhancing Engineering Design Skills in Introductory Engineering Design Courses. *International Journal of Engineering Education*, *13*(4). https://www.researchgate.net/publication/282929432

Kaldaras, L., Wang, K. D., Nardo, J. E., Price, A., Perkins, K., Wieman, C., & Salehi, S. (2024). Employing technology-enhanced feedback and scaffolding to support the development of deep science understanding using computer simulations. In *International Journal of STEM Education* (Vol. 11, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s40594-024-00490-7

Kartini Dwi. (2021). *Peningkatan Keterampilan Rekayasa, Minat Terhadap Sains Dan Teknologi, Komunikasi ilmiah SD Melalui Pembelajaran STEAM BerbasisTeknologi*. Universitas Pendidikan Indonesia.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. In *International Journal of STEM Education* (Vol. 3, Issue 1). Springer. https://doi.org/10.1186/s40594-016-0046-z

Kemendikbudristek. (2024). *Capaian Pembelajaran Kurikulum Merdeka*.

Kementrian Kesehatan Republik Indonesia. (2017). *Peraturan Menteri Kesehatan Republik Indonesia Nomor 32 Tahun 2017 tentang standar kualitas air layak pakai.*

Khahro, S. H., & Javed, Y. (2022). Key Challenges in 21st Century Learning: A Way Forward towards Sustainable Higher Educational Institutions. *Sustainability (Switzerland)*, *14*(23). https://doi.org/10.3390/su142316080

Khofi, M. B. (2024). The Green School Concept in Elementary Schools as an Effort to Form Sustainable Behavior and Environmental Awareness. *Jurnal Ilmiah Pendidikan Guru Madrasah Ibtidaiyah*, *14*(2), 206–225. https://doi.org/10.18952/aladzkapgmi.v14i2.14412

Khotimah, S. N., Anisa Mardhotillah, N., Arifaini, N., & Sumiharni. (2021). Karakterisasi Limbah Cair Greywater pada level Rumah Tangga Berdasarkan Sumber Emisi. *JURNAL SAINTIS*, *21*(02), 71–78. https://doi.org/10.25299/saintis.2021.vol21(02).7876

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice. *Journal of the Learning Sciences*, *12*(4), 495–547. https://doi.org/10.1207/S15327809JLS1204_2

Kurniawan, T., & Rosidin, U. (2024). Implementasi Pembelajaran STEM Berbasis Education for Sustainable Development pada Topik Energi Terbarukan untuk Meningkatkan Kemampuan Berpikir Sistem. *JoTaLP: Journal of Teaching and Learning Physics*, *9*, 12–22. https://doi.org/10.15575/jotalp.v9i1.28763

Kwon, H. (2016). Effect of middle school students' motivation to learn technology on their attitudes toward engineering. *Eurasia Journal of Mathematics, Science and Technology Education*, *12*(9), 2281–2294. https://doi.org/10.12973/eurasia.2016.1279a

Lally, P., Van Jaarsveld, C. H. M., Potts, H. W. W., & Wardle, J. (2010). How are habits formed: Modelling habit formation in the real world. *European Journal of Social Psychology*, *40*(6), 998–1009. https://doi.org/10.1002/ejsp.674

Lestari, D. (2017). *Pengaruh Pembelajaran Berbasis STEM Terhadap Keterampilan Rekayasa dan Penguasaan Konsep Siswa Pada Materi Pencemaran Udara*. Universitas Pendidikan Indoesia.

Lestari, E., & Nugraheni, N. (2024). Urgensi Sustainable Development Goals (SDGS) Dalam Penanganan Meningkatkan Sumber Daya Air Bersi Dan Sanitasi Layak Di Jakarta. In *Jurnal Ilmiah Sain dan Teknologi* (Vol. 2, Issue 4).

Li, C., Garza, T., Zhang, S., & Jiang, Y. (2023). Constructivist learning environment and strategic learning in engineering education. *Learning Environments Research*, *26*(3), 743–759. https://doi.org/10.1007/s10984-022-09450-w

Li, D., Zhao, L., Ma, S., Shao, S., & Zhang, L. (2019). What influences an individual's pro-environmental behavior? A literature review. *Resources, Conservation and Recycling*, *146*, 28–34. https://doi.org/10.1016/j.resconrec.2019.03.024

Mago, M., Yadav, M., Sharma, S., & Kaur, H. (2025). Environmental knowledge influencing pro-environmental behavior among university students: a serial mediation and MGA approach. *International Journal of Sustainability in Higher Education*, *26*(5), 1072–1095. https://doi.org/10.1108/IJSHE-02-2024-0110

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. In *International Journal of STEM Education* (Vol. 6, Issue 1). Springer. https://doi.org/10.1186/s40594-018-0151-2

Martín-Sánchez, A., González-Gómez, D., & Jeong, J. S. (2022). Service Learning as an Education for Sustainable Development (ESD) Teaching Strategy: Design, Implementation, and Evaluation in a STEM University Course. *Sustainability (Switzerland)*, *14*(12). https://doi.org/10.3390/su14126965

Maspul, K. A. (2024). Exploring STEM Education for Real-World Climate Change Concerns to Empower Students as Change Agents. *Journal of Physics Education and Science*, *1*(2), 12. https://doi.org/10.47134/physics.v1i2.249

Michalek, G., Thronicker, I., Yildiz, Ö., & Schwarze, R. (2019). Habitually green: integrating the concept of habit into the design of pro-environmental interventions at the workplace. *Nachhaltigkeits Management Forum | Sustainability Management Forum*, *27*(2), 113–124. https://doi.org/10.1007/s00550-019-00487-9

Mohtar, L. E., Halim, L., Abd Rahman, N., Maat, S. M., Iksan, Z. H., & Osman, K. (2019). A Model Of Interest In Careers Among Secondary School Students. *Journal of Baltic Science Education*, *18*(3), 404–416. https://doi.org/10.33225/jbse/19.18.404

Morris, J., Sassen, R., & McGuinness, M. (2023). Beyond water scarcity and efficiency? Water sustainability disclosures in corporate reporting. *Sustainability Accounting, Management and Policy Journal*, *14*(3), 490–514. https://doi.org/10.1108/SAMPJ-11-2021-0495

Mourtos, N. J. (2012). Defining, Teaching, and Assessing Engineering Design Skills. *International Journal of Quality Assurance in Engineering and Technology Education*, *2*(1), 14–30. https://doi.org/10.4018/ijqaete.2012010102

Mulyani, T. (2019). *Pendekatan Pembelajaran STEM untuk Menghadapi Revolusi Industry 4.0*.

Mustamin, K., Wahdah, W., Intiardy, D., Jumrah, A. M., & Pattiasina, P. J. (2024). The Impact of Project-Based Learning on Students' Collaboration Skills in Secondary Schools. *International Journal of Educational Research Excellence (IJERE)*, *3*(2), 992–998. https://doi.org/10.55299/ijere.v3i2.740

Nguyện, L. C., Hoa, H. Q., & Hien, L. H. P. (2025). Integrating design thinking into STEM education: Enhancing problem-solving skills of high school students. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(4), 1–11. https://doi.org/10.29333/ejmste/16084

Nourredine, H., Barjenbruch, M., Million, A., El Amrani, B., Chakri, N., & Amraoui, F. (2023). Linking Urban Water Management, Wastewater Recycling, and Environmental Education: A Case Study on Engaging Youth in Sustainable Water Resource Management in a Public School in Casablanca City, Morocco. *Education Sciences*, *13*(8). https://doi.org/10.3390/educsci13080824

Nuraeni, F., & Zahra, Z. N. (2021). Proyek Desain Rekayasa Dalam Pembelajaran IPA untuk Meningkatkan Collaborative Problem Solving dan Pemahaman Konsep. *LENSA (Lentera Sains): Jurnal Pendidikan IPA*, *11*(2), 47–59. https://doi.org/10.24929/lensa.v11i2.162

Nurbayani, D., Hindriana, A. F., & Sulistyono, S. (2023). Pembelajaran Berbasis Proyek Terintegrasi STEM (PjBL-STEM) Meningkatkan Keterampilan Rekayasa dan Sikap Kewirausahaan. *Quagga: Jurnal Pendidikan Dan Biologi*, *15*(1), 54–64. https://doi.org/10.25134/quagga.v15i1.6469

Nuryani, H. (2020). *Engineering Design Skills Dan Penguasaan Konsep Siswa Pada Materi Rekayasa Tanam Melalui Pembelajaran STEM*. Universitas Pendidikan Indonesia.

Odum, E. P., & Barrett, G. W. (2005). *Fundamentals of Ecology*. Cengage Learning.

Olsson, D., Gericke, N., & Chang Rundgren, S. N. (2016). The effect of implementation of education for sustainable development in Swedish compulsory schools – assessing pupils' sustainability consciousness. *Environmental Education Research*, *22*(2), 176–202. https://doi.org/10.1080/13504622.2015.1005057

Olsson, D., Gericke, N., Sass, W., & Boeve-de Pauw, J. (2020). Self-perceived action competence for sustainability: the theoretical grounding and empirical validation of a novel research instrument. *Environmental Education Research*, *26*(5), 742–760. https://doi.org/10.1080/13504622.2020.1736991

Osgood, L. (Elizabeth), & Johnston, C. R. (2022). Assessing Design Ability through a Quantitative Analysis of the Design Process. *Sustainability*, *14*(17), 10865. https://doi.org/10.3390/su141710865

Oyewo, O. A., Ramaila, S., & Mavuru, L. (2022). Harnessing Project-Based Learning to Enhance STEM Students' Critical Thinking Skills Using Water Treatment Activity. *Education Sciences*, *12*(11). https://doi.org/10.3390/educsci12110780

Pandowo, M. H. C., Tewal, B., Lengkong, V. P. K., & Wenas, R. S. (2021). Sustainable Behaviour In Higher Education: Antecedents And Consequences. *Journal of Sustainability Science and Management*, *16*(7), 80–92. https://doi.org/10.46754/jssm.2021.10.007

Pavlova, M., & Lomakina, T. (2016). Sustainable Development as a World-view: Implications for Education. In *Education in the Asia-Pacific Region* (Vol. 29, pp. 37–50). Springer Nature. https://doi.org/10.1007/978-981-287-940-0_4

Pinto, U., & Maheshwari, B. L. (2010). Reuse of greywater for irrigation around homes in Australia: Understanding community views, issues and practices. *Urban Water Journal*, *7*(2), 141–153. https://doi.org/10.1080/15730620903447639

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M. C., Gordon, B., Hunter, P. R., Medlicott, K., & Johnston, R. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on

low- and middle-income countries. *International Journal of Hygiene and Environmental Health*, *222*(5), 765–777. https://doi.org/10.1016/j.ijheh.2019.05.004

Purnami, I. A. O., & Widiadnya, I. G. N. B. Y. (2024). The Role of Project-Based Learning in Boosting Student Communication Confidence. *Jurnal Pendidikan Bahasa Inggris Undiksha*, *12*(3), 334–341. https://doi.org/10.23887/jpbi.v12i3.91586

Purwanto, M. Ngalim. (2019). *Prinsip-Prinsip dan Teknik Evaluasi Pengajaran*. Remaja Rosdakarya.

Purwianingsih, W., Widodo, A., Riandi, R., Sriyati, S., & Solihat, R. (2025). Pelatihan Desain Pembelajaran STEM-ESD untuk Guru SMA Wujudkan Hidup Berkelanjutan (STEM-ESD Learning Design Training for High School Teachers to Promote Sustainable Lifestyles). *Jurnal Pengabdian Kepada Masyarakat (YUMARY) SSN*, *5*(4), 843–856. https://doi.org/10.35912/yumary.v5i4.3658

Purzer, Ş., & Douglas, K. A. (2018). *Assessing Early Engineering Thinking and Design Competencies in the Classroom* (pp. 113–132). https://doi.org/10.1007/978-981-10-8621-2_7

Putra, A. K., Oktavia, I. A., Vanti, Q., Kristanti, D., Sari, N. Y., Amrullah, M. A., & Nabilah, G. E. (2024). Pengaruh Project Based Learning Berbasis Lingkungan Terhadap Literasi Lingkungan Peserta Didik. *Jurnal Pendidikan Dan Ilmu Pengetahuan*, *4*.

Qaa, & Advance HE. (2021). *Education for Sustainable Development Guidance*.

Qamar, K., Nchasi, G., Mirha, H. T., Siddiqui, J. A., Jahangir, K., Shaeen, S. K., Islam, Z., & Essar, M. Y. (2022). Water sanitation problem in Pakistan: A review on disease prevalence, strategies for treatment and prevention. In *Annals of Medicine and Surgery* (Vol. 82). Elsevier Ltd. https://doi.org/10.1016/j.amsu.2022.104709

Radzi, N. A. M., Olaleye, B. R., Saidi, N. A., Hassan, S., & Khumalo, N. (2025). Environmental Sustainability Awareness and Knowledge Among Millennial and Gen Z Students: A Study from a Public Higher Education Institution. *Journal of Lifestyle and SDGs Review*, *5*(4), e3931. https://doi.org/10.47172/2965-730x.sdgsreview.v5.n04.pe03931

Rajabzadeh, A. R., Long, J., Saini, G., & Zeadin, M. (2022). Engineering Student Experiences of Group Work. *Education Sciences*, *12*(5), 288. https://doi.org/10.3390/educsci12050288

Rukoyah, S. O. (2020). *Pembelajaran Berbasis STEM Untuk Membangun Keterampilan Rekayasa dan Kemampuan Engineering Productivity Siswa*. Universitas Pendidikan Indonesia.

Rusmana, A. N. (2017). *Implementasi Pembelajaran IPA Biologi Berbasis STEM dalam Meningkatkan Keterampilan Rekayasa dan Penguasaan Konsep Siswa SMP*. Universitas Pendidikan Indonesia.

Saefatu, J. F., & Rahmawati, A. (2023). Peran Masyarakat Konservasi Daerah Aliran Sungai (DAS) Bagian Hilir Desa Noelmina Kecamatan Takari Kabupaten Kupang. *Jurnal Geografi*, *19*(2).

Sánchez-García, R., & Reyes-de-Cózar, S. (2025). Enhancing Project-Based Learning: A Framework for Optimizing Structural Design and Implementation—A Systematic Review with a Sustainable Focus. *Sustainability*, *17*(11), 4978. https://doi.org/10.3390/su17114978

Sari, N. K., Heliawati, L., & Rubini, B. (2024). Analysis of Sustainable Awareness of Junior High School Students on Biotechnology Material. *Journal of Innovation in Educational and Cultural Research*, *5*(4), 556–567. https://doi.org/10.46843/jiecr.v5i4.1911

Sass, W., Boeve-de Pauw, J., Olsson, D., Gericke, N., De Maeyer, S., & Van Petegem, P. (2020). Redefining action competence: The case of sustainable development. *The Journal of Environmental Education*, *51*(4), 292–305. https://doi.org/10.1080/00958964.2020.1765132

Sass, W., De Maeyer, S., Boeve-de Pauw, J., & Van Petegem, P. (2023). Honing action competence in sustainable development: what happens in classrooms matters. *Environment, Development and Sustainability*, *25*(4), 3649–3670. https://doi.org/10.1007/s10668-022-02195-9

Sass, W., Pauw, J. B. de, Maeyer, S. De, & Petegem, P. Van. (2021). Development and validation of an instrument for measuring action competence in sustainable development within early adolescents: the action competence in sustainable development questionnaire (ACiSD-Q). *Environmental Education Research*, *27*(9), 1284–1304. https://doi.org/10.1080/13504622.2021.1888887

Schilhab, T. (2021). Nature Experiences in Science Education in School: Review Featuring Learning Gains, Investments, and Costs in View of Embodied Cognition. In *Frontiers in Education* (Vol. 6). Frontiers Media S.A. https://doi.org/10.3389/feduc.2021.739408

Setiawan, H., Koosbandiah Surtikanti, H., Kusnadi, K., & Riandi, R. (2023). Sustainability Awareness, Engagement, and Perception of Indonesian High School Students during Sustainability Project Based Learning

Implementation in Biology Education. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 4227–4236. https://doi.org/10.29303/jppipa.v9i6.3971

Siew, N. M., Amir, N., & Chong, C. L. (2015). The perceptions of pre-service and in-service teachers regarding a project-based STEM approach to teaching science. *SpringerPlus*, *4*(1), 1–20. https://doi.org/10.1186/2193-1801-4-8

Sintiya, A. M., Luthfi, E., & Ahsani, F. (2025). STEM-BASED EDUCATION FOR SUSTAINABLE DEVELOPMENT IN ELEMENTARY SCHOOLS: FOSTERING SUSTAINABILITY AWARENESS THROUGH A DESCRIPTIVE QUALITATIVE APPROACH. *Journal of Islamic Primary Education*, *8*(1), 74–85. http://journal.uinsgd.ac.id/index.php/al-aulad

Subheesh, N. P., & Sethy, S. S. (2020). Learning through assessment and feedback practices: A critical review of engineering education settings. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(3). https://doi.org/10.29333/ejmste/114157

Telešienė, A., Pauw, J. B. De, Goldman, D., & Hansmann, R. (2021). Evaluating an educational intervention designed to foster environmental citizenship among undergraduate university students. *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158219

Torlakson, T. (2014). *INNOVATE: A Blueprint for Science, Technology, Engineering, and Mathematics in California Public Education.* Californians Dedicated to Education Foundation. http://www.cde.ca.gov/RE/pn/rc/

Torsdottir, A. E., Olsson, D., & Sinnes, A. T. (2024). Developing action competence for sustainability – Do school experiences in influencing society matter? *Global Environmental Change*, *86*. https://doi.org/10.1016/j.gloenvcha.2024.102840

Tzanakakis, V. A., Paranychianakis, N. V., & Angelakis, A. N. (2020). Water supply and water scarcity. In *Water (Switzerland)* (Vol. 12, Issue 9). MDPI AG. https://doi.org/10.3390/w12092347

Umar, M. S. (2023). *Pengaruh Pembelajaran Project Rain Water Processing Berbasis STEM Terhadap Peningkatan Kesadaran dan Aksi Peduli Air Bersih Siswa SMA*. Universitas Pendidikan Indonesia.

UNESCO. (2017). *Education for Sustainable Development Goals : Learning Objectives*. United Nations Educational, Scientific and Cultural Organization UNESCO.

United National (UN). (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*.

Vanesa, A. A., Oktaviani, F., Wisuta, R., Nauli, S. I., Ananda, H., Pasa, A. P., Fadia Zahra Hanan, Salwa, N. A., & Nazhimah, S. (2025). Analisis Dampak Pencemaran Air Terhadap Lingkungan Sekitar dan Pertanggungjawabannya Dalam Perspektif Hukum Lingkungan. *Jurnal Penelitian Dan Pengabdian Masyarakat Indonesia*, *4*(1). https://dislhk.badungkab.go.id/artikel/17939-

Wals, A. E. J., Brody, M., Dillon, J., & Stevenson, R. B. (2014). Convergence Between Science and Environmental Education. *Science*, *344*(6184), 583–584. https://doi.org/10.1126/science.1250515

Waluyanti, S., Santoso, D., & Nurlayli, A. (2022). Improving Communication Skills Through Problem Project Based and Online Learning Integrated in Mpp Courses. In *Proceedings of the 9th International Conference on Education Research, and Innovation (ICERI 2021)* (pp. 198–207). Atlantis Press SARL. https://doi.org/10.2991/978-2-494069-67-1_22

West, S., van Kerkhoff, L., & Wagenaar, H. (2019). Beyond "linking knowledge and action": towards a practice-based approach to transdisciplinary sustainability interventions. *Policy Studies*, *40*(5), 534–555. https://doi.org/10.1080/01442872.2019.1618810

Widayati, S., Rochmah, S. N., & Zubedi. (2009). *Biologi SMA/MA Kelas X*.

Widodo, A. (2021). *Pembelajaran Ilmu Pengetahuan Alam Dasar-Dasar untuk Praktik* (1st ed.). UPI PRESS.

World Health Organization. (2017). *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating The First Addendum.*

World Intellectual Property Organization (WIPO). (2023). *Global Innovation Index 2023: innovation in the face of uncertainty*. World Intellectual Proper Organization (WIPO). https://doi.org/10.34667/tind.48220

Wynn, D. C., & Maier, A. M. (2022). Feedback systems in the design and development process. *Research in Engineering Design*, *33*(3), 273–306. https://doi.org/10.1007/s00163-022-00386-z

Xi, F., Ma, H., Pi, Z., Dong, Y., Sun, J., & Jin, R. (2024). Integrating the engineering design process into the conceive-design-implement-operate model for promoting high school students' STEM competence. *Educational Technology Research and Development*, *72*(4), 2267–2295. https://doi.org/10.1007/s11423-024-10377-7

Xing, X., & Ironsi, C. S. (2024). Implementing action competence teaching model as a framework for achieving sustainable development goals: insights from students. *International Journal of Sustainability in Higher Education*, *25*(5), 1048–1065. https://doi.org/10.1108/IJSHE-08-2023-0376

Yan, Q. S., Zhang, Z. Q., Er, C. X., & Wang, W. Q. (2024). The mechanism of internal and external efficacy influences residents' proenvironmental behavior through environmental willingness. *PLoS ONE*, *19*(3 March). https://doi.org/10.1371/journal.pone.0298378

Yanamandra, K., Chen, G. L., Xu, X., Mac, G., & Gupta, N. (2020). Reverse engineering of additive manufactured composite part by toolpath reconstruction using imaging and machine learning. *Composites Science and Technology*, *198*. https://doi.org/10.1016/j.compscitech.2020.108318

Zaharah, T. A., & E Moelyani, R. R. (2017). Reduksi Minyak, Lemak, dan Bahan Organik Limbah Rumah Makan Menggunakan Grease Trap Termodifikasi Karbon Aktif. *Jurnal Pengelolaan Lingkungan Berkelanjutan*, *1*(3), 25–32. http://www.bkpsl.org/ojswp/index.php/jplbhttp://www.bkpsl.org/ojswp/index.php/jplb

Zaini, A., Gunawan, Z., & Khaer, A. (2024). Strategies for Successful Developing a Sustainable Behavior Management Culture as an Identity of Quality Education. *Proceeding of International Conference on Education, Society and Humanity*, *02*(01).