

Enhancing Vocational Students' Milling Machining Skills through Challenge-based Project Learning Using Coconut Shell-based Polymer Products

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ABSTRACT

Procedural milling instruction often limits vocational students' technical decision-making and exposure to sustainable materials. This study examined changes in milling performance and learning experiences through challenge-based project learning using coconut-shell polymer composite workpieces. A mixed-methods design combined a one-group pretest-posttest study, classroom observations, and semi-structured interviews. Twenty students participated in six learning stages: challenge orientation, material investigation, process planning, milling execution, product evaluation, and sustainability reflection. Five students were interviewed. Mean performance scores increased from 61.05 (SD = 3.53) to 78.15 (SD = 4.28), $t(19) = 33.37$, $p < .001$, with 80% achieving mastery. Qualitative findings indicated improved confidence, problem-solving, participation, independence, creativity, and sustainability awareness. Students addressed machining difficulties through trial cuts, parameter adjustments, workholding checks, dimensional inspection, peer discussion, and lecturer guidance. These preliminary findings suggest promising educational benefits, although the small sample and absence of a control group limit causal conclusions.



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Introduction

Vocational mechanical engineering education is expected to prepare learners not only to operate machines but also to interpret design requirements, plan processes, make quality-oriented decisions, and respond to uncertainty in manufacturing settings Billett (2011). Milling is therefore

a central competence because it integrates technical drawing interpretation, cutting-tool selection, spindle speed and feed determination, depth-of-cut planning, workholding, measurement, safety, and product evaluation Setiadi et al (2017). These capabilities are increasingly important as machining systems become more digitally connected and technologically adaptive Sutopo et al (2020).

In many vocational workshops, however, students still complete teacher-defined operations by following predetermined steps. This procedural approach may produce basic operational fluency without adequately developing the reasoning needed to select parameters, diagnose surface defects, correct dimensional deviations, or justify a clamping strategy. Active and project-based learning can address this limitation by engaging students in decision-making, production, reflection, and the creation of assessable artifacts (Bell, 2010; Guo et al., 2020; Kokotsaki et al., 2016; Prince, 2004).

Challenge-based learning extends this orientation by organizing learning around authentic, open-ended problems that require investigation, solution development, action, evaluation, and reflection. Reviews of higher and engineering education describe student agency, collaboration, real-world relevance, and iterative solution development as central features of the approach (Doulougeri et al., 2024; Gallagher and Savage, 2023; Leijon et al., 2022; Leles et al., 2024). Its contextual emphasis is also compatible with vocational and teaching-factory environments in which learning is linked to concrete production challenges Wahjusaputri and Bunyamin (2021).

This approach is particularly relevant to machining education. Machining is a situated activity shaped by product requirements, material behavior, machine capability, tool condition, operator judgment, process control, and inspection. When students produce a real component rather than an isolated exercise piece, they must connect planning with execution and revise decisions in response to observable process outcomes. Project-oriented machining activities have similarly been used to strengthen participation and applied problem solving in CNC learning Sutopo et al (2024).

Vocational curricula must also embed sustainability in practical decision-making rather than treat it as a separate theoretical topic. Sustainability competence develops when learners connect systems thinking, material choice, action, and reflection in authentic educational contexts (Brundiers et al., 2021; Lozano et al., 2017; Wiek et al., 2011). Workshop-based product development offers an opportunity to make these connections visible through the selection and processing of waste-derived materials.

Coconut-shell particles and powder have potential as fillers in polymer composites because they can support lightweight, value-added, and resource-efficient products (Nadzri et al., 2022; Sarki et

al., 2011). Their machining is nevertheless technically demanding. Studies of natural-fiber and bio-filler polymer composites identify parameter sensitivity, surface-integrity problems, tool-material interaction, burrs, pull-out, heterogeneity, and variation in machinability as recurring concerns (Masoud et al., 2020; Vinayagamoorthy and Rajmohan, 2018; Wang et al., 2019). These characteristics make coconut-shell polymer composites a meaningful medium for adaptive machining practice.

Despite these developments, prior studies have largely examined challenge-based learning, vocational machining, sustainability competence, and coconut-shell composites as separate topics. Limited evidence explains how a challenge-based project can use a waste-derived polymer composite to develop milling performance while simultaneously revealing students' technical difficulties and sustainability-related learning. This unresolved intersection constitutes the research gap addressed in the present study.

Accordingly, this study integrates challenge-based project learning with milling practice using coconut-shell polymer composite workpieces. Its novelty lies in treating the sustainable material not merely as a workpiece but as a source of authentic manufacturing uncertainty that prompts planning, troubleshooting, quality control, and reflection. The study addressed the following research questions:

- a. How did students' milling performance change after challenge-based project learning?
- b. What technical challenges emerged when students milled coconut-shell polymer composite workpieces, and how did they address them?
- c. How did the project shape students' understanding of sustainability-oriented manufacturing?

Method

Research Design

This study used a mixed-methods design that combined a quantitative one-group pretest-posttest component with an exploratory qualitative component (Creswell and Plano Clark, 2018; Sugiyono, 2012). The quantitative component measured within-group change in milling performance, while observations and interviews were used to explain how students experienced the project and responded to the material and machining challenges. The design is represented as:

$$O_1 \text{ X } O_2 \dots\dots\dots (1)$$

where O_1 is the pretest, X is the six-stage challenge-based project intervention using coconut-shell polymer composite workpieces, and O_2 is the posttest.

Because the study did not include a control or comparison group, the design estimated change within one class but could not isolate the intervention from practice, maturation, instructor, or contextual effects Shadish et al (2002). Consequently, the quantitative findings were interpreted as preliminary evidence of association rather than definitive evidence of causation. The qualitative component examined the learning processes underlying the observed change.

Participants and Research Context

The participants were 20 vocational students enrolled in a milling class. They had completed introductory learning in machining theory, technical drawing, measurement, workshop safety, and basic milling operations, but had limited experience with non-conventional composite materials. All 20 students completed the pretest, intervention, and posttest. The study was conducted during practical learning on pocket making and basic milling. Students were asked to manufacture a small product or component from a coconut-shell polymer composite workpiece while meeting specified dimensional, surface-quality, and safety requirements. The material was selected because it represented locally available waste that could be transformed into a value-added product.

Instruments and Data Collection

The quantitative instrument was a milling machining performance rubric. The rubric assessed students' technical drawing interpretation, tool selection, cutting parameter planning, workholding, machine operation, dimensional measurement, surface quality evaluation, workshop safety, and troubleshooting ability. Scores were converted into a 0–100 scale. Qualitative data were collected through observation and semi-structured interviews. Observation focused on students' active participation, independence, creativity, collaboration, and technical reflection during the milling project. Interviews were conducted with five selected students to explore their perceptions of the project, technical challenges, problem-solving strategies, and understanding of sustainable manufacturing.

Preparation of Coconut-Shell Polymer Composite Workpieces

The workpieces were prepared before the learning intervention through a vacuum-infusion/casting sequence. Coconut-shell profiles and shell-derived filler were arranged in a thermoset mold and impregnated with a polymer matrix under vacuum. After curing, the workpieces were removed from the mold and prepared as machinable blanks. Before milling, students visually inspected each blank for surface texture, edge integrity, stiffness, possible brittleness, and visible heterogeneity; these observations informed conservative initial cutting and clamping decisions.

Instruments and Data Collection

Quantitative performance was assessed with a milling rubric covering technical-drawing interpretation, tool selection, cutting-parameter planning, workholding, machine operation, dimensional measurement, surface-quality evaluation, workshop safety, and troubleshooting. Scores were converted to a 0-100 scale and the mastery criterion was set at 75. Qualitative data were collected through structured classroom observation and semi-structured interviews. Observation focused on participation, independence, creativity, collaboration, and technical reflection. Five students were selected purposively to represent contrasting performance levels and observable participation or creativity. Interviews examined their perceptions, technical difficulties, adjustment strategies, and understanding of sustainable manufacturing.

Data Analysis

Quantitative data were summarized using the mean, standard deviation, minimum, maximum, and individual gain score. A paired-samples t-test assessed the pretest-posttest difference, and Cohen's d was reported as a standardized measure of change. The analysis used a significance threshold of $p < .05$. Qualitative data were analyzed thematically through familiarization, initial coding, theme development, review, and interpretation (Braun & Clarke, 2019; Miles et al., 2014). Codes focused on technical confidence, parameter adjustment, workholding, surface quality, participation, independence, creativity, collaboration, and sustainability awareness. Observation records and interview excerpts were compared to refine the themes.

Result

Developed Challenge-Based Project Model for Milling Practice

The implemented challenge-based project model comprised six stages: challenge orientation, product and material investigation, machining process planning, milling execution, product evaluation, and reflective sustainability discussion.

a. Stage 1: Challenge Orientation

Students received a manufacturing challenge: transform a coconut-shell polymer composite blank into a precise, functional, and visually acceptable product. The task emphasized material uncertainty, dimensional accuracy, surface quality, and function.

b. Stage 2: Product and Material Investigation

Students examined the drawing and inspected the workpiece's texture, edge condition, stiffness, possible brittleness, and visible heterogeneity before selecting an initial machining

strategy.

c. Stage 3: Machining Process Planning

Students identified critical dimensions, selected tools, proposed spindle speed, feed, and depth of cut, planned the operation sequence, and justified the workholding method.

d. Stage 4: Milling Execution

Students performed the milling operations under safety supervision and monitored cutting response, vibration, clamping stability, surface condition, and dimensional deviation. The lecturer used guiding questions instead of prescribing every step.

e. Stage 5: Product Evaluation

Students compared the finished workpiece with the drawing and evaluated dimensional accuracy, edge condition, surface quality, appearance, function, and safety compliance.

f. Stage 6: Reflective Sustainability Discussion

Students reviewed their technical decisions and discussed how coconut-shell waste could be converted into a value-added manufacturing material.

Table 1 summarizes the learning activities, milling applications, and expected competence at each stage. The sequence was designed to move students from a teacher-directed routine toward an iterative manufacturing problem.

Table 1. Syntax of the Challenge-Based Project Learning Model in Milling Machining

<i>Syntax</i>	<i>Learning Activity</i>	<i>Example of Implementation in Milling Practice</i>	<i>Expected Competence</i>
Challenge orientation	Students receive a real manufacturing challenge	Producing a coconut shell-based polymer product with accurate dimensions and acceptable surface quality	Understanding the manufacturing problem
Product and material investigation	Students examine product design and material characteristics	Observing texture, stiffness, edge behavior, and machining feasibility	Material awareness and product analysis
Machining process planning	Students plan tools, parameters, sequence, and workholding	Selecting end mill, spindle speed, feed rate, depth of cut, and clamping method	Technical planning and decision-making
Milling execution	Students perform machining and observe process behavior	Milling surfaces, slots, edges, or contours while monitoring vibration and surface quality	Machine operation and adaptive control
Product evaluation	Students inspect product quality	Measuring dimensions, checking surface quality, identifying defects	Quality control and product evaluation
Reflective sustainability discussion	Students reflect on technical and ecological meaning	Discussing coconut shell waste as value-added material	Sustainability-oriented manufacturing awareness

The six-stage sequence was feasible for the class because the challenge combined a concrete product, an unfamiliar material, and measurable technical criteria.

Quantitative Results

All 20 students completed the performance assessment. Figure 1 presents the individual pretest, posttest, and gain scores, and Table 2 summarizes the descriptive statistics.

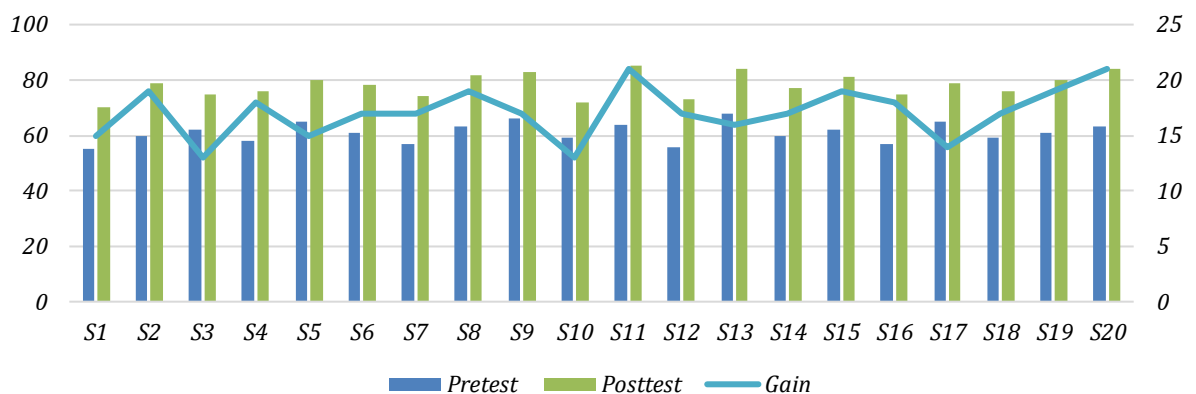


Fig 1. Individual Pretest, Posttest, and Gain Scores for Milling Performance

The mean score increased from 61.05 (SD = 3.53) at pretest to 78.15 (SD = 4.28) at posttest. The mean individual gain was 17.10 points (SD = 2.29), with gains ranging from 13 to 21 points. Descriptive Statistics for Pretest, Posttest, and Gain Scores explain in Table 2.

Table 2. Descriptive Statistics for Pretest, Posttest, and Gain Scores

Score Component	Mean	SD	Minimum	Maximum
Pretest	61.05	3.53	54	68
Posttest	78.15	4.28	70	85
Gain	17.10	2.29	13	21

The paired-samples t-test indicated a statistically significant pretest-posttest difference, $t_{(19)} = 33.37$, $p < .001$. The mean difference was 17.10 points (95% CI [16.03, 18.17]), and the standardized change was large (Cohen's $d = 7.46$). Given the small, uncontrolled design, this estimate should be interpreted in conjunction with the study limitations. Paired-Samples t-Test Result in Table 3.

Table 3. Paired-Samples t-Test Result

Comparison	Mean Difference	<i>t</i>	<i>df</i>	<i>p</i>	95% CI	Cohen's <i>d</i>
Pretest–Posttest	17.10	33.37	19	< .001	16.03–18.17	7.46

No student met the mastery criterion of 75 at pretest. At posttest, 16 of 20 students (80%) met or exceeded the criterion. Thus, the intervention was associated with higher within-group performance and a substantial increase in mastery attainment.

Qualitative Findings from Student Interviews

Five students were interviewed: students with comparatively low and high performance and students who displayed distinctive participation or creativity during practice. Three themes were identified: technical confidence, adaptive problem solving, and sustainability awareness. Representative excerpts are presented below.

a. Increased Technical Confidence

Students reported greater confidence because they were expected to propose and justify technical decisions rather than wait for complete procedural directions.

“Before this project, I usually waited for the lecturer to tell me the speed, feed, and cutting depth. In this project, I had to think first and explain why I chose the parameter. It made me more confident because I understood the reason behind the process.” (ST1)

ST1’s account shows a shift from dependence on instructor-provided parameters to reasoned selection. Because students were more familiar with aluminum and steel, the composite workpiece initially made them uncertain about suitable parameter ranges.

“I became more careful in reading the drawing because the product had to be accurate. If I made a mistake in understanding the dimension, the final product would not fit the design.” (ST4)

Together, the excerpts indicate that confidence developed through the connection between drawing interpretation, parameter choice, execution, and inspection rather than through machine operation alone.

b. Adaptive Problem-Solving during Machining

Students experienced the most difficulty with surface roughness, cutting aggressiveness, clamping pressure, vibration, and dimensional control. These difficulties required repeated observation and adjustment.

“The material was different from aluminum or steel. The surface could become rough if the cutting was too aggressive. We had to reduce the depth of cut and check the surface again.” (ST1)

Students who encountered rough surfaces responded by reducing the depth of cut, moderating the feed, making trial cuts, and rechecking the surface before continuing. This iterative response made the material’s behavior part of the learning process.

“The most difficult part was clamping. If it was too tight, I was afraid the product would be damaged. If it was not tight enough, the workpiece vibrated.” (ST3)

c. Sustainability Awareness through Product Manufacturing

The project also broadened students' understanding of coconut-shell waste as a manufacturing resource rather than merely a discarded natural material.

"I did not expect coconut shell waste could become a product material. After machining it, I understood that waste can have value if we design and process it correctly." (ST5)

ST5 connected material processing with value creation, showing that sustainability became understandable through a completed manufacturing task.

"This project made me think that machining practice does not always have to use metal. Local waste materials can also be used for learning and product development." (ST2)

Observational Findings: Active Participation, Independence, and Creativity

Observation records showed increasing participation, independence, and creativity. Early in the project, students frequently requested direct instructions; later, they discussed tools, parameters, clamping, process sequence, inspection, and finishing with less lecturer direction. Table 4 summarizes these observations. Observation Results during Challenge-based Project Implementation explain in Table 5.

Table 5. Observation Results during Challenge-based Project Implementation

<i>Observed Aspect</i>	<i>Indicators</i>	<i>Observation Findings</i>
Active participation	Asking questions, discussing machining decisions, engaging in product evaluation	Students actively discussed tool selection, parameter choice, and machining problems during practice
Independence	Making decisions without waiting for full instruction	Students began to determine cutting parameters, clamping methods, and inspection steps independently
Creativity	Proposing alternative product forms, adjusting process strategy, improving finishing	Students proposed design adjustments, modified machining sequences, and explored finishing alternatives
Collaboration	Sharing tasks and giving peer feedback	Students worked collaboratively during planning, machining, measurement, and reflection
Technical reflection	Identifying errors and suggesting improvements	Students reflected on surface defects, dimensional deviation, and workholding problems

The observed behaviors indicate a more student-centered workshop environment in which students diagnosed problems, tested adjustments, shared feedback, and evaluated the consequences of their decisions.

Discussion

The intervention was associated with a statistically significant within-group increase in milling performance, from a mean of 61.05 to 78.15, and with 80% posttest mastery. The result is consistent

with evidence that active and project-based learning supports engagement, applied decision-making, reflection, and artifact-based performance (Guo et al., 2020; Prince, 2004). However, the absence of a control group prevents attributing the observed change exclusively to the intervention.

The learning task required students to move beyond procedural compliance. They selected and justified parameters, observed process consequences, inspected the product, and revised decisions. This cycle is important in vocational education because workplace competence includes judgment and adaptation as well as task execution Billett (2011).

The six-stage model operationalized central features of challenge-based learning: an authentic challenge, student agency, collaborative inquiry, iterative solution development, evaluation, and reflection (Doulougeri et al., 2024; Gallagher and Savage, 2023; Leijon et al., 2022; Leles et al., 2024). Its contribution is a concrete syntax for applying these features to vocational milling rather than to a general design or classroom problem.

The coconut-shell polymer composite functioned as more than a substitute workpiece. Its heterogeneous response introduced uncertainty in workholding, surface quality, cutting intensity, and dimensional control. These difficulties are consistent with reported machinability concerns in natural-fiber polymer composites, including surface damage, pull-out, parameter sensitivity, and tool-material interaction (Masoud et al., 2020; Vinayagamoorthy and Rajmohan, 2018; Wang et al., 2019).

The qualitative evidence explains how students responded to that uncertainty. Those who initially struggled did not resolve the problem through a single prescribed parameter; they used trial cuts, reduced depth of cut, moderated feed, checked clamping, remeasured dimensions, discussed alternatives with peers, and acted on lecturer prompts. The challenge therefore elicited an iterative troubleshooting process that would be largely absent from a fully predetermined exercise.

Students also reported stronger technical confidence because they understood why a decision was made. This supports a broader view of machining competence as an integration of planning, execution, control, evaluation, and improvement. The model situated machine operation within this complete manufacturing cycle.

Observation further indicated greater participation, independence, creativity, and collaboration. Students asked technical questions, proposed alternative sequences or design adjustments, and reflected on defects. Such behaviors align with evidence that project-, problem-, and challenge-based approaches connect knowledge, action, and reflection in engineering education

(Bell, 2010; Kokotsaki et al., 2016; Sukacké et al., 2022).

The project also supported sustainability awareness by allowing students to experience waste valorization through material processing and manufacturing. Coconut-shell fillers have documented potential in polymer composite products (Nadzri et al., 2022; Sarki et al., 2011), but the pedagogical value emerged when students connected this potential with design decisions, machining constraints, and product quality.

This experiential connection is consistent with sustainability-education frameworks that emphasize systems thinking, action, and applied competence rather than knowledge alone (Brundiars et al., 2021; Lozano et al., 2017; Wiek et al., 2011). In this study, sustainability was made tangible through the conversion of a local waste-derived material into a finished component.

The findings suggest four curriculum implications. Milling tasks can be organized around authentic products rather than isolated exercise pieces; assessment can include planning, reasoning, troubleshooting, collaboration, and reflection in addition to final product quality; locally available waste-derived materials can connect technical learning with sustainability; and lecturers can use guiding questions to support student decisions without removing productive difficulty.

Several limitations qualify these findings. First, the one-group pretest-posttest design lacked a control group; therefore, practice, maturation, instructor influence, and other contextual factors cannot be ruled out. Second, the sample comprised only 20 students from one class, which limits statistical power and generalizability. Third, interviews involved five purposively selected students, and observations were conducted in a single setting. Fourth, the study did not experimentally compare resin systems, material formulations, surface roughness, tool wear, or environmental performance. Larger controlled studies, repeated implementations, validated performance instruments, and technical characterization of the composite are needed.

Conclusion

This study developed and implemented a six-stage challenge-based project model for milling coconut-shell polymer composite workpieces: challenge orientation, product and material investigation, machining process planning, milling execution, product evaluation, and reflective sustainability discussion. The sequence positioned milling as an authentic manufacturing problem rather than a routine procedural exercise.

Students' mean performance increased from 61.05 to 78.15, and 16 of 20 students met the posttest mastery criterion. These results indicate a strong within-group improvement associated

with the intervention, but they do not establish a causal effect because the study used a small sample without a control group.

Interview and observation findings showed stronger technical confidence, adaptive problem solving, participation, independence, creativity, collaboration, and sustainability awareness. Students overcame material-related difficulties through iterative cutting, workholding, inspection, discussion, and reflection. The composite therefore served both as a manufacturing material and as a pedagogical trigger for troubleshooting and waste-valorization learning.

Future studies should compare the model with conventional instruction or another active-learning approach, involve larger and multi-site samples, and examine retention and transfer of machining competence. Technical studies should also report and test the composite formulation, machinability, surface roughness, tool wear, mechanical properties, and environmental performance.

References

- Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 83(2), 39–43. <https://doi.org/10.1080/00098650903505415>
- Billett, S. (2011). *Vocational education: Purposes, traditions and prospects*. Springer. <https://doi.org/10.1007/978-94-007-1954-5>
- Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4), 589–597. <https://doi.org/10.1080/2159676X.2019.1628806>
- Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron, G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., & Zint, M. (2021). Key competencies in sustainability in higher education—Toward an agreed-upon reference framework. *Sustainability Science*, 16, 13–29. <https://doi.org/10.1007/s11625-020-00838-2>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE.
- Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*, 113(4), 1076–1106. <https://doi.org/10.1002/jee.20588>

- Gallagher, S. E., & Savage, T. (2023). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education*, 28(6), 1135–1157. <https://doi.org/10.1080/13562517.2020.1863354>
- Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, 102, Article 101586. <https://doi.org/10.1016/j.ijer.2020.101586>
- Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, 19(3), 267–277. <https://doi.org/10.1177/1365480216659733>
- Leijon, M., Gudmundsson, P., Staaf, P., & Christersson, C. (2022). Challenge based learning in higher education—A systematic literature review. *Innovations in Education and Teaching International*, 59(5), 609–618. <https://doi.org/10.1080/14703297.2021.1892503>
- Leles, A., Zaina, L. A. M., & Cardoso, J. R. (2024). Challenge-based learning for competency development in engineering education: A PRISMA-based systematic literature review. *IEEE Transactions on Education*, 67(5), 746–757. <https://doi.org/10.1109/TE.2024.3417908>
- Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability*, 9(10), Article 1889. <https://doi.org/10.3390/su9101889>
- Masoud, F., Sapuan, S. M., Mohd Ariffin, M. K. A., Nukman, Y., & Bayraktar, E. (2020). Cutting processes of natural fiber-reinforced polymer composites. *Polymers*, 12(6), Article 1332. <https://doi.org/10.3390/polym12061332>
- Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). SAGE.
- Nadzri, S. N. I. H. A., Sultan, M. T. H., Shah, A. U. M., Safri, S. N. A., Talib, A. R. A., Jawaid, M., & Basri, A. A. (2022). A comprehensive review of coconut shell powder composites: Preparation, processing, and characterization. *Journal of Thermoplastic Composite Materials*, 35(12), 2641–2664. <https://doi.org/10.1177/0892705720930808>
- Prince, M. J. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223–231. <https://doi.org/10.1002/j.2168-9830.2004.tb00809.x>
- Sarki, J., Hassan, S. B., Aigbodion, V. S., & Oghenevweta, J. E. (2011). Potential of using coconut shell particle fillers in eco-composite materials. *Journal of Alloys and Compounds*, 509(5), 2381–2385.

<https://doi.org/10.1016/j.jallcom.2010.10.041>

- Setiadi, B. R., Setuju, & Suparmin. (2017). Quality determining of machining products based on manufacturing industry standards: An exploration survey of vocational students. *VANOS Journal of Mechanical Engineering Education*, 2(2), 105–116.
- Shadish, W. R., Cook, T. D., & Campbell, T. D. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Houghton Mifflin.
- Sugiyono. (2012). *Metode penelitian kuantitatif, kualitatif, dan R&D*. Alfabeta.
- Sukackè, V., Guerra, A. O. P. de C., Ellinger, D., Carlos, V., Petronienè, S., Gaižiūnienè, L., Blanch, S., Marbà-Tallada, A., & Brose, A. (2022). Towards active evidence-based learning in engineering education: A systematic literature review of PBL, PjBL, and CBL. *Sustainability*, 14(21), Article 13955. <https://doi.org/10.3390/su142113955>
- Sutopo, S., Setiadi, B. R., & Hanzla, M. (2020). Upgrading manual turning machine towards IoT-based manufacturing. *Jurnal Pendidikan Teknologi dan Kejuruan*, 26(2), 155–161. <https://doi.org/10.21831/jptk.v26i2.27334>
- Sutopo, S., Setiadi, B. R., Prasetya, T. A., Harjanto, C. T., Sasongko, B. T., & Saputri, V. H. L. (2024). Peer-project-based learning in CNC simulation programming courses. *TEM Journal*, 13(4), 3079–3085. <https://doi.org/10.18421/TEM134-42>
- Vinayagamoorthy, R., & Rajmohan, T. (2018). Machining and its challenges on bio-fibre reinforced plastics: A critical review. *Journal of Reinforced Plastics and Composites*, 37(16), 1037–1050. <https://doi.org/10.1177/0731684418778356>
- Wahjusaputri, S., & Bunyamin. (2021). Challenge of teaching factory based on school's potentials in West Java during the COVID-19 pandemic. *Turkish Journal of Computer and Mathematics Education*, 12(7), 2209–2217.
- Wang, D., Onawumi, P. Y., Ismail, S. O., Dhakal, H. N., Popov, I., & Silberschmidt, V. V. (2019). Machinability of natural-fibre-reinforced polymer composites: Conventional vs. ultrasonically assisted machining. *Composites Part A: Applied Science and Manufacturing*, 119, 188–195. <https://doi.org/10.1016/j.compositesa.2019.01.019>
- Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6, 203–218. <https://doi.org/10.1007/s11625-011-0132-6>