

ORIGINAL

Interconnection of Reverse Engineering Learning with Small and Medium Enterprises: An Inspiration for Impactful Collaborative Product Design

Interconexión del aprendizaje de ingeniería inversa con pequeñas y medianas empresas: una inspiración para el diseño colaborativo de productos de gran impacto

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ABSTRACT

The problem of small and medium enterprises (SMEs) in Indonesia is very comprehensive regarding product design. They have local products but experience constraints in quality and innovation in market competition. Collaborative approaches with universities have been pursued even though they have only been realised through collaborative research. This research aims to apply reverse engineering learning with industry to produce optimal new product designs through Computer Aided Design (CAD). The research method uses research and development with a mixed-method approach, where this research combines the development of a reverse engineering learning model and applies it in the classroom. To solve partner problems, the stage of developing a learning model was carried out by involving seven validators from academia and professionals. Research is also directed to testing the effectiveness of reverse engineering learning models based on industrial products with existing learning models, with a post-test-only control design. The results of testing validators and students in the experimental class showed significant results. Interrater reliability validators agree that the model built is constructive and valid. There were significant differences with the existing learning model at the time of testing. These results reveal that the resulting recommendations in CAD learning provide advantages for universities and SMEs. For students, the reverse engineering learning model based on industrial products can improve their learning outcomes, and for SMEs, it is a recommendation for enhancing the quality and product diversification.

Keywords: Reverse Engineering Learning; Small and Medium Enterprises; Collaborative Product Design.

RESUMEN

El problema de las pequeñas y medianas empresas en Indonesia es muy amplio en lo que respecta al diseño de productos. Cuentan con productos locales, pero experimentan limitaciones en la calidad y la innovación en el mercado competitivo. Se han buscado enfoques colaborativos con universidades, aunque estos solo se han materializado mediante investigación colaborativa. Esta investigación busca aplicar el aprendizaje de ingeniería inversa con la industria para producir diseños óptimos de nuevos productos mediante Diseño Asistido por Computadora (CAD). El método de investigación utiliza investigación y desarrollo con un enfoque de métodos mixtos, donde esta investigación combina el desarrollo de un modelo de aprendizaje de ingeniería inversa con su aplicación en el aula. Para resolver los problemas de los socios, la etapa de desarrollo de un modelo de aprendizaje se llevó a cabo con la participación de siete validadores académicos y profesionales.

La investigación también se dirige a probar la efectividad de los modelos de aprendizaje de ingeniería inversa basados en productos industriales con los modelos de aprendizaje existentes, con un diseño de control basado únicamente en la prueba posterior. Los resultados de las pruebas realizadas a validadores y estudiantes en la clase experimental mostraron resultados significativos. Los validadores de confiabilidad entre evaluadores coinciden en que el modelo construido es constructivo y válido. Se observaron diferencias significativas con el modelo de aprendizaje existente en el momento de la prueba. Estos resultados revelan que las recomendaciones resultantes del aprendizaje de CAD ofrecen ventajas para universidades y pymes. Para los estudiantes, el modelo de aprendizaje de ingeniería inversa basado en productos industriales puede mejorar sus resultados de aprendizaje y para las PYME, es una recomendación para mejorar la calidad y la diversificación de productos.

Palabras clave: Aprendizaje de Ingeniería Inversa; Pequeñas y Medianas Empresas; Diseño Colaborativo de Productos.

INTRODUCTION

Small and Medium Enterprises (SMEs) have problems with product design innovation. This result impacts product quantity.⁽¹⁾ In terms of quality, SMEs are strongly influenced by the speed of innovation,⁽²⁾ so achieving a transformation change depends on the commitment of SMEs to strive to advance integratively. SMEs have a big task in optimising local resources to produce competitive products. It seems this is still not massively done because management dynamics depend highly on change reforms, mainly research and development.

Limited design human resources are an inhibiting factor for low product design innovation. The lack of experience in reverse engineering also determines the slow pace of innovation. This slow development is due to the rules of a company that require the courage to optimise and restructure existing products to improve in real-time and continuously.⁽³⁾ This development is also reflected in Indonesia, where SMEs face hefty business competition as part of developing competitive local products, but have difficulty penetrating the national market due to the quantity and quality of products. The protection of SMEs' local designs and products has progressed based on the Presidential Instruction of the Republic of Indonesia to increase domestic content derived from SMEs. This support opens the door for SMEs to accelerate new product design to increase the quantity of domestic product diversification. The Ministry of Industry noted that there are still 388 products originating from within the country with a content value of 25 % - 40 %. This value is still unsatisfactory because the expected target is far from it. Of course, this is an additional task for SMEs to contribute to achieving the targets set every year.

Efforts to improve the productivity performance of SMEs are strongly supported by the research and development division's ability to realise various quality products to meet consumer needs. The R&D division is a high investment for the company because that is where productivity values grow and develop rapidly.⁽⁴⁾ This effort also seems to be still not optimal, with the existence of human resources in very limited SMEs, especially for product innovation.⁽⁵⁾ The tendency is for SME owners to work hard to produce innovations so that the products produced do not come from the correct product design.

One of the efforts to accelerate product innovation through quality design involves collaboration with universities.⁽⁶⁾ This effort is a benchmark for the progress of an SME that can cooperate with partners from universities as parties who develop product designs. Lecturers or academics often conduct product design development activities in general and fundamentally. They strive to improve quality and productivity through systematic research and development steps. However, the presence of this strategy has not become a strategic effort because the number of products produced is still less than expected by SMEs. There needs to be a comprehensive effort to support SMEs in increasing productivity and diversifying their products to a better size and quality.

The innovative learning approach is an exciting learning trend in vocational education in Indonesia. Learning involving industry cooperation is the basis for mutually beneficial cooperation between universities and SMEs. Project-based learning allows students to hone their creativity and innovation, and be challenged to work on a project from the industry.^(7,8,9) The development of learning based on industrial product design is limited to product redesign, and there has been no follow-up to strive for the product to be more optimal and not violate intellectual property. Product redesign learning that develops in Indonesia is widely applied to CAD learning, which uses industrial products to be redrawn based on measurement accuracy.

The phenomenon of CAD learning that is developing today still needs to be expanded in function so that it has an impact on interested parties. These parties are SMEs that need the opportunity to take advantage of student design results, but do not violate regulations. CAD learning tends to be one-sided, and the researchers confirmed to SMEs that what universities do in CAD learning does not significantly impact productivity and

product diversification. They expect the growth of new products based on the results of student creativity and innovation in reverse engineering. Not just product redesign, but how CAD learning can be a recommendation for SMEs to improve their products' quality and productivity. If this can be realised significantly, SMEs will be more confident in producing local products that are varied and internationally competitive.^(10,11)

The reverse engineering techniques developed in engineering circles are often applied using manual measurement techniques and 3D scanners.⁽¹²⁾ Manual measurements for students can be done using mechanical and digital measuring instruments, although the results are slightly different, but insignificant. Manual measurements have calculation errors when reading the size and calibration points of measuring instruments that are not appropriate or not done by students, so what is done in CAD learning can later be combined with digital measuring instruments.

The breakthrough linking SME product problems to 3D CAD learning through reverse engineering learning methods is an essential solution in overcoming product design variations. The selected industrial products significantly impact SMEs in improving their product quality. These products are used as learning objects for students to provide solutions to SME problems. Students are expected to be able to reverse engineer and optimise other industrial products to be imitated, developed, and optimised so that they are not the same as existing products. The reverse engineering learning model is a bridge to accelerate the fulfilment of the quantity of SME industrial product designs. This model is expected to be the main alternative to improve 3D CAD competency based on real industrial problems and take concrete steps in evaluating industrial products as learning materials.

METHOD

Research Design

This research uses research and development with a mixed-method approach. The research begins with developing a reverse engineering learning model based on industrial products. The development step is geared towards model validation and testing, model testing using experimental methods with a posttest-only control design. This experimental design meets the needs of researchers, as both control classes and experiments are carried out post-test.⁽¹³⁾ To measure the difference between existing and reverse engineering learning models based on industrial products. Using two classes as a comparison indicator of learning models is chosen randomly and does not refer to any recommendations. The experimental design at the time of model testing is set out in table 1,

Table 1. Model testing experiment design		
Group/Class	Treatment	Posttest
Experiment	X (Industrial Product-based Reverse Engineering Learning Model)	EAT (Learning Outcome)
Control	- (Existing Learning Model)	YC (Learning Outcome)

The control and experimental classes are two different classes. Both achieve learning outcomes determined by lecturers and researchers. Still, the difference is the application of the learning model that the existing learning model that develops in the classroom is described in the results of research observations.

Research subjects

This research involved students taking 3D CAD courses at the Mechanical Engineering Education Study Program at Yogyakarta State University. A total of 2 classes were involved in the study to divide them into control and experimental classes. The control class had 16 students, and the experimental class has 18 students. Based on gender and experience using CAD software, the two classes have the following distribution.

Table 2. Research respondent profile						
Group	Sex		CAD Operating Experience			
	Men	Woman	< 1 year	1 - 2 years	3 - 5 years	> 5 years
Experiment	16	2	10	4	4	0
Control	14	2	8	5	2	1

Table 2 shows that the data distribution can be known relatively evenly by sex and student experience. Experience refers to the time students have been exposed to CAD, as the learning process varies, with input from both vocational and high schools. This data was obtained from a pretest questionnaire containing information related to respondents' identities, including their experience operating CAD. This identification is essential to

publish so that the initial conditions of the class can be identified more informatively, and researchers do not need to try to achieve data homogeneity.

Data Collection Techniques

Qualitative and quantitative data support a series of studies developing a reverse engineering learning model based on industrial products. Qualitative data is used to create the model and tools for the reverse engineering learning model based on industrial products. The data collection technique utilises expert review and validation to obtain a fit model. The model review and validation involved substantive experts from academia, particularly in product design learning, vocational learning evaluation, and product design learning technology. The validation also considered assessments from CAD, reverse engineering, and CAE industry practitioners. All validators were validated using the Delphi technique, which brings researchers and validators together independently through a guided review.⁽¹⁴⁾ The data used primarily assesses how the model and its tools are evaluated by experts, so that the review results can be used as input for model improvements. These experts will determine based on their respective expertise. For example, CAD experts will comprehensively assess the product design process, from sketching, 3D modelling, and detailed drawing.

Quantitative data were obtained through classroom model testing. The control and experimental classes were administered with an initial pretest and a final posttest. The pretest served as an initial assessment of students' existing conditions before the model was implemented, while the posttest served as a post-treatment measurement. The test data collection technique aligns closely with the researchers' expectations regarding the differences in learning outcomes in 3D CAD courses between existing learning methods and product design-based reverse engineering learning methods.

Data Analysis Techniques

Data analysis to answer research formulations using a quantitative approach. In testing the validity of reverse engineering learning models based on industrial products, rater assessment as a reliability assessment is used as an analysis to ensure that model construction, model devices, and model evaluation can produce good agreements. This technique is suitable for ensuring consistency and diversity in assessments from various assessors or validators in providing advice on model development—inter-rater assessment using the Intraclass Correlation Coefficient (ICC). To provide this assessment, validators must delve into the model and its tools and conduct assessments based on their expertise. This method was chosen because the number of validator assessors is large, and the assessment scores are continuous. The results are analysed by providing average values in a simple tabulation table.

Data analysis was performed on the model effectiveness test with an independent sample T-test. Each control group and experiment were tested through posttests in partial and overall analysis. This analysis is used to conclude whether the reverse engineering learning model based on industrial products differs from the existing one. In addition, the average trend of student learning outcomes is also used as a reference for whether there is a change in the average value between the control class and the experiment.

RESULTS

Industrial product-based reverse engineering learning models are developed from the preparation of model construction, model device development and implementation, and model effectiveness testing. The systematic procedure is carried out based on the orientation of learning needs in the classroom and the usefulness of the design to diversify SME products.

Model syntax construction

Constructing reverse engineering learning models based on industrial products adopts the step of team-based project development. A team-based project is a collaborative method of learning using a project approach.^(15,16,17) This method optimises team performance in completing a given project. There are seven syntax models that instructors and students use in learning 3D CAD, including group formation, determination of industrial products, reinstallation of industrial products, redesign of existing products, optimisation of new designs, embodiment of detailed drawings, and project presentations. The systematic sequence of syntax procedures and implementation mechanisms is described as follows.

Group formation

Students form groups based on the number available in the classroom. At least 4 to 5 students in each reverse engineering group. Each group has an even distribution of tasks based on the abilities of the members organised in a group. The group consists of 1 person in the measurement section, one in the 3D modelling design section, one in the simulation and optimisation of the design, and one in the part of making detailed drawings. Each group determines the group coordinator, who serves as the presenter of the design project. The mechanism of work and interrelation of each group organisation is as follows.

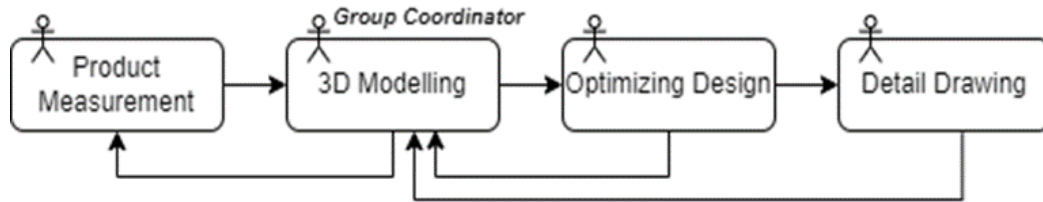


Figure 1. The mechanism of action of each individual in the group

An organised work system, as shown in figure 1, shows that everyone's tasks and functions can run effectively even with a performance load. One of the divisions was appointed as the coordinator of the group. A division that is competent and masters all aspects of 3D modelling, so it is worthy of being a group coordinator. The coordinator ensures that the process from the beginning to the end of the lecture can run according to the syntax of the model implemented.

Industrial Product Determination

Determining design projects derived from industrial products is the responsibility of each group. The instructor provides direction through limited course learning outcomes and group guidance to determine industrial products. Students are allowed to explore industrial products with high reverse engineering potential. The instructor and representatives of the SME R&D department provide recommendations for potential imported products for students to use as material for reverse engineering consideration. The student group determines 2-3 alternative industrial products for reverse engineering.

Students and SME representatives jointly explore design by referring to the need assessment instrument. The criteria in reverse engineering refer to the product's suitability with the learning outcomes of the 3D CAD course, the level of manufacturability in prototyping by SMEs, the number of parts in the combined product assembly, and market potential based on the perspective of SMEs.

Remeasurement of Existing Products

Industrial products determined with SMEs are then carefully and accurately remeasured. Industrial metrology competencies for students have been obtained at the beginning of their studies. The measurement technique uses manual and digital instruments with 0,01 - 0,05 mm accuracy. Reverse engineering for more sophisticated capacities can use portable 3D scanners or stands. Students sketch out known dimensions in the initial draft of the design. Other fellow students validate and check the accuracy of measurements and the completeness of the dimensions that have been measured.

Redesign of Existing Products

Comprehensively scalable products with various limits and tolerances are further visualised in 3D modelling drawings on CAD software. 3D modelling begins with creating a 2D sketch drawing concerning X and Y coordinates drawn on the Z axis to form a 3D image. If there is more than one component, the redesigned parts are assembled by taking into account the location of the part, its function, and connectivity with other parts. This process is through an integrated group organisation work mechanism where students in the group provide suggestions and reviews of the results of the 3D modelling design work that has been produced.

3D design computerised through CAD software is continued by analysing the boundary conditions of the forces acting on the component. Computer-aided Engineering (CAE) analysis through the Finite Element Analysis (FEA) approach is carried out by students to see the extent of the condition of components with data sheet-based materials and 3D designs based on the effects of loading channels. The simulation results produced in the design product are used as a baseline in developing product innovation through reverse engineering. The group manages data, design information, and simulations as initial data on existing industrial product conditions.

New Design Optimisation

Students carry out a phase of creativity and innovation at this stage. The stage that emphasises the development element of improving the quality of existing designs is discussed effectively and collaboratively between student groups. Students create new designs by paying attention to existing designs based on weaknesses produced in simulations, as well as the manufacturability of SMEs and more eye-catching new products.

Starting the design optimisation process is almost the same as the fourth step. Students do 3D modelling using CAD software by sketching products, making 2D sketches, presenting 3D modelling views, and conducting loading simulation analysis on predetermined boundary conditions areas. Students in groups jointly formulate new product sketches known by SMEs so that SMEs can monitor the design process. Students' sketches are then

visualised in 3D modelling with predetermined parts. Complete 3D modelling results are simulated on CAE software for FEA analysis. Loading and contact between components are carried out carefully and precisely so that the results can be compared. Suppose the results obtained are not significant with the initial design. In that case, the innovation step of the new product redesign is repeated by referring to the fatal critical point produced in the simulation.

Embodiment of detail drawing

Designs optimised and with high innovation value are then outlined in working drawings. This image is a series of isometric images and detailed views that clarify the image's meaning and dimensions. The presentation of detailed drawings uses the International Standard Organisation (ISO) approach of component dimensions, tolerances, adjustments, and image captions to reinforce information in detailed drawings. Aspects of presentation, visualisation of the arrangement of the drawing area, use of dimensional details, and thickness of lines are considered as determining factors for the success of the detailed drawing assessment.

Project Presentation

The final stage in the syntax of the industrial product-based reverse engineering learning model is for students to present the results of their projects in groups. The presentation began with students conducting the need assessment process, designing and collecting initial data on existing product simulations, and optimising new designs. Instructors and SMEs assess the feasibility of design quality to see how much the industry can use new product designs. At this stage, students must hone interpersonal and communication skills in promoting the results of their projects to assessors and users.

Assessment Between Model Raters

Inter-rater assessment refers to the conclusion questions that are limited to 5 gradations of the Likert assessment. Each validator can provide ratings and comments to dive deep into the answers and improve their models and tools if needed. The validators involved are experts in product design learning, vocational learning evaluation, product design learning technology, CAD, reverse engineering, and product design. The selection of validators is based on experience and expertise pursued for at least five years, so the quality of model development can be credible. The summary of the assessment from each validator regarding the evaluation of model syntax, its tools, clarity of guidance, and potential sustainability is presented in table 3.

Validation Item	Product Design Learning	Evaluation	Educational Technology	CAD	Reverse Engineering	CAE
Systematics of Model Syntax	5	4	3	5	5	4
Model Device Equipment	4	3	4	4	4	4
Clarity of the Model Use Guidebook	4	3	3	4	3	3
Potential for Program Sustainability	4	3	3	4	3	4

Referring to table 3, it can be shown that the assessment of validators generally reaches the lowest value of 3 and the highest of 5. Equally, the achievements of each validator show somewhat similar consistency. The proof is based on the tabulation of the average score of each validator, as stated in figure 2.

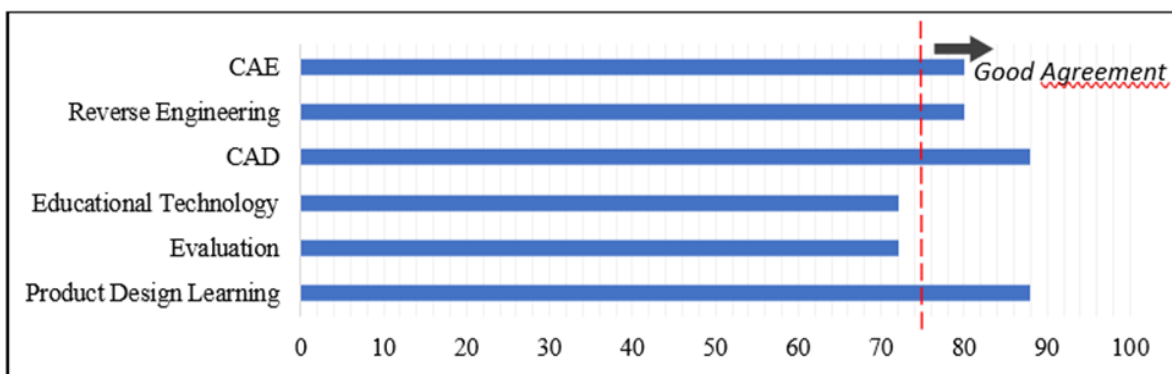


Figure 2. Inter-Rater Assessment

Figure 2 shows the highest rating in CAD and product design learning. Although validators are different people, the result for both is to ensure that the model constructed with the device seems to align with the product design concept. Things that are still low and need to be evaluated next are validators in educational technology and evaluation. Both provide recommendations for using modern facilities and more complete measurement instruments. The findings are based on information in the guidebook for applying reverse engineering learning models based on industrial products.

A joint analysis was also carried out on the seven validators using the ICC. This analysis uses SPSS to determine how consistent the validators are when combined. The results of the validation are listed in table 4 below.

Intraclass Correlation		95 % Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Say
Single Measures	0,446a	0,063	0,932	5,833	3	15	0,008
Average Measures	0,829c	0,288	0,988	5,833	3	15	0,008

Based on the results of the inter-rater reliability analysis in table 4, information can be obtained that the validity of the validators of reverse engineering learning models based on industrial products is categorised as excellent. Based on the compared kappa value, a score of 0,829 has exceeded 0,8 to indicate high inter-rater quality. The difference between raters in producing model assessment quality is at a significance level of 0,017 with a quality measure below 0,05, which shows that no party influence the data between raters.

The research review above shows that expert validators have constructively tested the reverse engineering learning model based on industrial products. Improvement of each substance in the model is carried out based on direct suggestions and review notes so that the quality of the model and its completeness are declared valid and ready to be implemented in actual class conditions.

The Effectiveness of Industrial Product-Based Reverse Engineering Learning Models in CAD Learning

This effectiveness testing involves two research classes: control and experimental. The control class is a class that applies the usual learning methods that lecturers apply. Based on observations of learning in the control class. The learning method used tends to be drilling techniques by referring to the job sheet provided by the lecturer. Students only continue with the lecturer's instructions as stated on the job sheet. Students in other classes will apply a reverse engineering learning model based on industrial products for the experimental class. All students will be examined using complex 3D modelling teaching materials in inhomogeneous conditions. Effectiveness testing looks at differences in student learning outcomes in control and experimental classes in table 5.

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	95 % Confidence Interval of the Difference	
							Lower	Upper
Equal variances assumed		2,264	0,142	-2,751	32	0,010	-11,627	-1,734
Equal variances are not assumed.				-2,696	26,614	0,012	-11,769	-1,592

Based on the results of tabulation using SPSS in the independent t-test (table 5), the data of both classes are declared homogeneous. This homogeneity can be seen from the significance value of Levene's test of 0,142, which is more than the significance level set by Levene's test, which is 0,05. The homogeneous data shows no specific differentiator for the two classes used. Although the number of students in each class differs, the quality of students is rated the same in the Levene test. The difference between classes can be seen in the value of the independent sample t-test, which has a significance value (2-tailed) of 0,01. This value indicates a significant difference between the control and experimental classes because the value of the accepted hypothesis decision is less than 0,05. The score obtained has shown that the two research classes will differ in results based on the learning method applied.

The resulting differences from each class must be aligned based on the mean value and standard deviation. Descriptive data based on tabulations of learning achievement of control and experimental class students are contained in table 6 below.

Table 6. Mean and Standard Deviation Differences between Groups

Group	N	Mean	Std. Deviation	Std. Error Mean
Control	16	80,88	8,253	2,063
Experiment	18	87,56	5,823	1,373

Referring to table 6, it can be explained that there is an increase in the average score of CAD 3D courses for students in the experimental class. The difference of 6,68 is significant enough to improve students' design skills. However, when referring to the standard deviation distribution of each class, the control class has a reasonably substantial deviation compared to the experimental class. This is because student learning scores have a range of values far enough to cause the standard deviation to be significant. Unlike the experimental class, the standard deviation value obtained is an effort to improve the quality of learning, where the distribution of deviations begins to narrow and approach many aggregate scores. The lowest and highest values that are almost close together make the standard deviation value low in the experimental class.

DISCUSSION

This study confirms that industrial product-based learning through a reverse engineering approach can improve students' creativity, innovation, and learning outcomes in computer-aided design (CAD).⁽¹⁸⁾ Collaboration between universities and industry, especially SMEs, has been proven to provide relevant, real-world experiences, so that students not only master technical concepts but also understand the actual needs of the industrial world.⁽¹⁹⁾ The study results show that this model encourages students to be more critical in exploring designs, develop comprehensive competencies, and provide applicable solutions to product design problems faced by the industry.⁽²⁰⁾

These findings indicate that integrating reverse engineering into industrial product-based learning effectively bridges the gap between academic theory and industrial practice. This aligns with research showing that project-based learning can enhance critical thinking, problem-solving, and collaboration skills.^(21,22) In this context, reverse engineering is relevant because students learn to analyse existing products, identify their weaknesses, and then redesign them to meet industry needs.^(23,24) This mechanism encourages a take-and-give process.⁽²⁵⁾ Industry receives innovative input to improve product quality, while students gain authentic experience in solving design problems. Thus, lecturers act as both facilitators⁽²⁶⁾ and transformers,⁽²⁷⁾ Ensuring the learning process is collaborative, reflective, and has a real impact.

The results of this study have important implications for the development of vocational higher education curricula, particularly for study programs related to product design and manufacturing. First, this model can be an innovative learning alternative that accommodates the industry and workplace needs. Second, collaboration with SMEs allows universities to directly contribute to increasing the competitiveness of local products through design innovation. Third, reverse engineering-based learning encourages the formation of a creative ecosystem where students, lecturers, and industry exchange knowledge, experiences, and benefits.⁽²⁸⁾ Thus, this model impacts student competency and accelerates the transfer of technology and innovation to the small industry sector.

Although the research results show positive impacts, several limitations should be noted. First, the implementation of this model is still limited to collaboration with small and medium-sized enterprises (SMEs), so generalisation to larger industries requires further study. Second, the readiness of partner industries is a key determinant of success.⁽²⁹⁾ Some SMEs may not yet have the capacity to collaborate intensively with universities. Third, this research emphasises CAD design aspects, so application to other fields requires methodological adaptations. Furthermore, evaluating student learning outcomes focuses on cognitive aspects and the final product, so the affective dimension and the collaboration process have not been fully measured. Therefore, further studies need to expand the industry scope, deepen the evaluation instruments, and examine the long-term impact of this model on the competitiveness of local products and students' readiness to enter the workforce.

CONCLUSIONS

This study shows that reverse engineering-based learning with industrial products significantly improves students' learning outcomes, particularly in analytical skills, creativity, and innovation in CAD design. Students can produce design solutions relevant to industrial needs through learning stages that include group formation, product selection, reinstallation, redesign, design optimisation, detailed drawing realisation, and project presentation. Comparison with classes using conventional learning models shows a significant increase in students' ability to understand and solve real industrial problems. These findings underscore the importance of integrative learning models that involve collaboration between universities and SMEs. Industrial project-based learning provides academic benefits in the form of improved student competency and makes a tangible

contribution to supporting innovation and the competitiveness of local products. Therefore, the industrial product-based reverse engineering model holds strategic value as a bridge between higher education and the business world and is a crucial part of creating a sustainable innovation ecosystem.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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