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Developing a Spin Coating Equipment Manual to Enhance Laboratory Literacy for Quality Higher Education

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ABSTRACT

This study aimed to develop and evaluate a spin coating operational manual oriented toward improving students' laboratory literacy at Universitas Negeri Surabaya. The study employed a Research and Development approach using the 4-D model: Define, Design, Develop, and Disseminate. The manual was designed for a custom-built spin coater based on Arduino and ESP32 and covered thin-film concepts, equipment components, occupational safety and health, standard operating procedures, process parameters, troubleshooting, maintenance, and calibration. Three validators assessed the manual, after which a limited student trial was conducted using pretest-posttest laboratory literacy assessment and a student response questionnaire. Expert validation produced an overall validity score of 93.48%, classified as very valid. The mean laboratory literacy score increased from 60.10 on the pretest to 90.75 on the posttest, with an N-gain of 0.77, indicating a high improvement category. The highest N-gain occurred in the using dimension (0.84), followed by communicating (0.81), understanding (0.77), and evaluating (0.65). Student responses reached 95.55%, classified as very good. The novelty of the study lies in positioning a standardized operational manual for a custom-built spin coater not only as technical guidance but also as a learning resource that explicitly supports laboratory literacy, safe practice, and greater user independence.

INTRODUCTION

Higher education plays a strategic role in developing competent, adaptive, and competitive human resources. At Universitas Negeri Surabaya, strengthening practice- and laboratory-based learning is part of the effort to improve educational quality. This direction is consistent with Sustainable Development Goal 4, particularly the emphasis on quality education and the development of relevant skills for higher education and employment (UNESCO, 2017). Laboratory activities are important in science education because they connect conceptual understanding with empirical experience and support scientific literacy, practical skills, and safety awareness. Scientific literacy itself includes the ability to identify problems, explain scientific phenomena, and draw conclusions from evidence (OECD, 2013; Susanti & Ishafit, 2023).

Within laboratory-based learning, laboratory literacy is especially important because students must understand the functions of equipment, follow procedures correctly, and work safely. Previous literature shows that laboratory literacy can remain low among learners, particularly in identifying equipment functions and understanding laboratory safety. Zuhaida and Imaduddin (2019) reported that 60% of first-year prospective science teachers were in the low laboratory-literacy category, while Linawati et al. (2021) similarly highlighted limitations in equipment recognition and safety understanding. These conditions indicate the need for systematic and contextual learning resources that can be used directly during laboratory work.

To address this gap, laboratory literacy in this study is conceptualized across four core dimensions: understanding, using, evaluating, and communicating (OECD, 2019). The understanding dimension encompasses students' conceptual comprehension of equipment operation, including the fundamental working principles of the instrument, familiarity with control interfaces, and the theoretical effect of operating parameters such as rotational speed and spin time (Seery, 2020; Tyona, 2013). The using dimension reflects procedural and practical competencies, involving compliance with occupational safety and health (OSH) protocols, work area preparation, pre-operational equipment inspection, accurate parameter configuration, real-time process monitoring, and systematic shutdown procedures (Ménard & Trant, 2020). The evaluating dimension emphasizes higher-order diagnostic and analytical skills, such as assessing parameter stability (e.g., RPM consistency), correlating operating conditions with product outcome quality, identifying root causes of operational defects, and selecting appropriate troubleshooting strategies (Seery, 2020). Finally, the communicating dimension addresses scientific documentation and expression, requiring students to accurately record experimental logs, articulate technical procedures using proper scientific terminology, and formulate evidence-based conclusions and optimization recommendations (OECD, 2019).

Spin coating is one laboratory technique that requires both conceptual and procedural competence. It is widely used in materials physics, chemistry, and engineering to prepare thin films. The process involves high rotational speed, precise parameter settings, and the use of chemical solutions, so users must understand both operating procedures and safety requirements. Previous studies describe the application of spin coating for thin-film preparation and emphasize the importance of controlling process conditions (Ahzan et al., 2021; El Mahboub et al., 2024; Soonmin, 2021).

The equipment used in this study is a custom-built spin coater developed in earlier research using a microcontroller and IoT-based data monitoring and storage (Sya'roni et al., 2022). Preliminary observations in the laboratory showed that students frequently asked laboratory staff about operating procedures, parameter settings, and safety steps. Students also showed inconsistent implementation of personal protective equipment and safe operating procedures. Because the custom-built instrument did not have a standardized written manual, users depended heavily on oral instructions, which could reduce consistency and increase the possibility of operational errors.

Therefore, this study developed a spin coating operational manual that integrates technical guidance with laboratory literacy. The novelty lies in designing the manual specifically for the custom-built instrument and systematically orienting its content toward the four core dimensions of laboratory literacy. The objectives of this study were to: (1) describe the development process of the spin coating manual; (2) determine the validity of the manual in terms of content, language, presentation, and design; and (3) examine its potential to improve students' laboratory literacy and obtain student responses to its use.

RESEARCH METHOD

This study used a Research and Development approach. The development process followed the 4-D model consisting of Define, Design, Develop, and Disseminate. The approach was selected because it provides a structured sequence for identifying needs, designing a product, validating its validity, and examining its use in an authentic context (Sugiyono, 2021; Arkadiantika et al., 2020; Maydiantoro, 2021).

In the Define stage, primary and secondary data were gathered through observations and interviews with students and laboratory staff. Student characteristics were considered to adjust the language and depth of the manual. Concept analysis covered the operating principle of the spin coater, standard operating procedures, and laboratory safety. The development objectives were then formulated with an explicit focus on improving laboratory literacy.

In the Design stage, the collected information was discussed and organized into a draft manual. The manual was designed to include basic thin-film concepts, introduction to the spin coater, physical components and technical specifications, occupational safety and health, standard operating procedures, parameter settings, troubleshooting, maintenance, and calibration. The draft was then prepared for expert validation.

In the Develop stage, the draft was evaluated by three validators. Ten validation aspects were assessed: content, structure/systematics, material presentation, graphics/illustrations, color, typography, layout, spelling and grammar, sentence structure, and readability. Each item used a five-point Likert scale. The percentage validity score was calculated from the obtained score divided by the maximum score and multiplied by 100%. A score of 81-100% was categorized as very valid, 61-80% as valid, 41-60% as quite valid, 21-40% as not valid, and below 21% as very invalid (Wagiran, 2013; Sujarweni, 2014; Arikunto & Abdul Jabar, 2009).

In the Disseminate stage, the revised manual was used in a limited trial involving 20 undergraduate students. Students used the manual while operating the spin coater. Laboratory literacy was measured before and after use, and student responses were collected after the activity. The laboratory-literacy rubric covered four dimensions: understanding, using, evaluating, and communicating. Occupational safety and health practices were also observed during tool use.

Improvement in laboratory literacy was analyzed using normalized gain: N-gain = (posttest score - pretest score) / (maximum score - pretest score). The report classified N-gain values above 0.70 as high, values between 0.30 and 0.70 as moderate, and values below 0.30 as low (Riduwan, 2015). Student responses were analyzed descriptively using the percentage of the obtained score relative to the maximum score. The response questionnaire covered readability, ease of use, and usefulness; 81-100% was categorized as very good.

RESULTS AND DISCUSSION

Development of the Manual and Expert Validation

The development process produced a manual entitled "Panduan Penggunaan Spin Coater berbasis Arduino dan ESP32 untuk Laboratorium MIPA dan Teknik." The manual

was structured to move from conceptual foundations to operational practice. It included basic thin-film concepts, equipment introduction, component descriptions, safety procedures, standard operating procedures, parameter settings, troubleshooting, maintenance, and calibration. In addition to step-by-step instructions, the manual explains the influence of RPM, spin time, solution viscosity, solution volume, and environmental conditions on thin-film results. This structure was intended to help students understand not only what to do but also the scientific rationale behind each stage of operation.

Expert validation showed consistently high scores across all ten assessed aspects, as presented in Table 1. The overall score was 617 out of a maximum of 660, corresponding to 93.48% and the very valid category. The highest average scores were found for structure/systematics, color, and readability, each at 4.92. Spelling and grammar had the lowest average score, 4.33, but still fell within the very valid category. These results indicate that the manual was sufficiently developed in content, presentation, design, language, and readability to proceed to the limited student trial.

Table 1. Expert validation results for the spin coating operational manual

Aspect	Mean	Percentage	Category
Content suitability	4.52	90.5%	Very valid
Structure/systematics	4.92	98.3%	Very valid
Material presentation	4.58	91.7%	Very valid
Graphics/illustrations	4.53	90.7%	Very valid
Color	4.92	98.3%	Very valid
Typography	4.67	93.3%	Very valid
Layout	4.75	95.0%	Very valid
Spelling and grammar	4.33	86.7%	Very valid
Sentence structure	4.75	95.0%	Very valid
Readability	4.92	98.3%	Very valid
Overall	**-**	**93.48%**	**Very valid**

Improvement in Students' Laboratory Literacy

The limited trial showed a substantial increase in students' laboratory literacy. The total mean score increased from 60.10 on the pretest to 90.75 on the posttest, a difference of 30.65 points. The resulting N-gain was 0.77, which was classified as high. Table 2 presents the results for the four laboratory-literacy dimensions.

Table 2. Pretest-posttest laboratory literacy results by dimension

Dimension	Pretest	Posttest	Pretest (%)	Posttest (%)	N-gain	Category
Understanding	14.70/25	22.60/25	58.80	90.40	0.77	High
Using	26.75/40	37.90/40	66.88	94.75	0.84	High
Evaluating	9.90/20	16.45/20	49.50	82.25	0.65	Moderate
Communicating	8.75/15	13.80/15	58.33	92.00	0.81	High
Total/Mean	**60.10/100**	**90.75/100**	**60.10**	**90.75**	**0.77**	**High**

The highest gain occurred in the using dimension (0.84). This pattern is consistent with the operational function of the manual: students could directly follow guidance on personal protective equipment, preparation of the work area, equipment inspection, RPM and spin-time settings, process monitoring, and shutdown procedures. Several individual indicators also showed strong changes, such as the use of personal protective equipment and preparation of the work area from 3.20 to 4.90, equipment inspection from 3.00 to 4.90, and process monitoring from 3.20 to 4.90.

The understanding dimension reached an N-gain of 0.77. Students' understanding of the basic spin coating principle rose from 3.10 to 4.90, knowledge of buttons and menus from 3.05 to 4.85, and understanding of the effect of RPM and spin time from 3.15 to 4.90. These changes indicate that the manual functioned as more than a procedural checklist; it also supported conceptual understanding of how the instrument operates.

The evaluating dimension produced a moderate N-gain of 0.65, lower than the other three dimensions. Students improved in assessing RPM stability, linking process conditions to thin-film quality, identifying causes of operational problems, and selecting responses to abnormal conditions. However, the lower gain suggests that evaluation requires more complex reasoning than following a defined procedure. This study therefore identifies evaluation and troubleshooting as areas that could be strengthened through additional cases and problem-solving exercises.

The communicating dimension reached an N-gain of 0.81. Students improved in recording equipment-use data from 2.95 to 4.95 and in explaining procedures and results using appropriate technical language from 2.95 to 4.80. The ability to formulate conclusions and optimization recommendations also increased from 2.85 to 4.05. Taken together, the data provide descriptive evidence that the manual has strong potential to support laboratory literacy. Because this study does not include a control group or inferential statistical testing, the findings are interpreted as potential improvement rather than a causal effect.

Student Responses to the Operational Manual

Student responses were grouped into readability, ease of use, and usefulness. The overall response score was 95.55% and classified as very good. The detailed results are shown in Table 3.

Aspect	Items	Mean score	Percentage	Category
Readability	6	4.87	97.33%	Very good
Ease of use	7	4.74	94.86%	Very good
Usefulness	7	4.74	94.71%	Very good
Overall	**20**	**4.78**	**95.55%**	**Very good**

Readability received the highest percentage (97.33%). Students gave particularly high scores to the clarity of technical terms and the systematic order of chapters, both 4.95, while language clarity scored 4.85 and typography/layout comfort scored 4.90. This indicates that the organization and presentation of the manual supported access to information during laboratory activities.

Ease of use reached 94.86%. The occupational safety and emergency-response section received a score of 4.95, ease of finding information scored 4.90, and guidance for RPM and spin-time settings scored 4.85. The item concerning the sequence of standard operating procedures had the lowest score in this aspect, 4.20. Although still positive, this result identifies the SOP presentation as a specific target for further simplification or visual clarification.

Usefulness reached 94.71%. Students rated the overall usefulness of the manual for improving the effectiveness and quality of laboratory activities at 5.00. Perceived improvement in understanding the working principle, equipment components, and safe operation each scored 4.90. Lower scores of 4.40 were obtained for reducing dependence on oral instructions from laboratory staff and increasing confidence to operate the equipment independently. These responses indicate that the manual can reduce reliance on oral guidance but does not fully replace the role of trained laboratory staff, particularly for less experienced users.

CONCLUSION

The study produced a spin coating operational manual based on Arduino and ESP32 using the 4-D development process. Expert validation yielded an overall validity score of 93.48%, placing the manual in the very valid category. In the limited student trial, the mean laboratory literacy score increased from 60.10 to 90.75, with an N-gain of 0.77 in the high category. The strongest improvement occurred in the using dimension (0.84), while evaluating showed a moderate gain (0.65) and remains an area for further strengthening. Student responses reached 95.55% and were classified as very good, with especially strong ratings for readability, safety guidance, and overall usefulness. These findings indicate that the manual has strong potential to support safer, more systematic, and more independent laboratory learning. Further refinement should focus on simplifying the presentation of standard operating procedures and enriching evaluation and troubleshooting activities. The interpretation remains descriptive because the present study does not include a control group or inferential testing.

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