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Developing an Arduino–Tinkercad Teaching Module to Support Virtual Practicum and Learning Outcomes in Grade XII Informatics Education

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ABSTRACT

Practical Arduino learning in Grade XII Informatics is intended to develop students' computational thinking, programming literacy, and problem-solving skills through hands-on activities. However, many schools face limitations in equipment availability, practicum time, and component maintenance, which restrict students' opportunities for repeated practice. To address these challenges, this study developed an Arduino teaching module integrated with Tinkercad Circuits as a virtual practicum resource. This study employed a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, and Disseminate). The study was conducted at SMA Negeri 4 Surabaya and involved two expert lecturers, two Informatics teachers, five students in a small-group trial, and 33 students in a large-group trial. Data were collected through validation sheets, practicality questionnaires, and pretest–posttest instruments. Data were analyzed using Aiken's V, descriptive statistics, category distribution, and normalized gain (N-gain). The developed module demonstrated high validity, with an average Aiken's V of 0.861 (range = 0.750–1.000). Practicality results indicated that the module was very practical according to teachers ($M = 4.24$), small-group students ($M = 4.40$), and large-group students ($M = 4.47$). In the large-group trial, 87.88% of students rated the module as very practical. Students' learning outcomes improved from a pretest mean of 50.24 ($SD = 8.11$) to a posttest mean of 75.33 ($SD = 10.87$), yielding a moderate N-gain of 0.520. The findings indicate that the Arduino–Tinkercad teaching module is valid, practical, and moderately effective in supporting virtual Arduino practicum activities. The module provides a safe, accessible, and repeatable learning environment and offers a feasible alternative when physical Arduino equipment is limited.

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1. INTRODUCTION

The rapid advancement of digital technologies has transformed educational practices and increased the importance of Informatics education in preparing students for the demands of the twentyfirst century. Beyond learning how to use technology, students are expected to develop computational thinking, programming literacy, problem-solving skills, and the ability to design technology-based solutions for real-world problems. Computational thinking has been recognized as a fundamental competence that enables learners to formulate problems, organize information logically, develop algorithmic solutions, and evaluate outcomes systematically (Wing, 2006). Consequently, Informatics education should provide students with opportunities to engage actively in designing, testing, and refining technological solutions rather than merely acquiring theoretical knowledge (Grover & Pea, 2013; Shute et al., 2017).

One instructional approach that supports these goals is physical computing. Physical computing integrates programming with electronic hardware, allowing learners to observe how software instructions influence the behavior of physical devices. Through hands-on activities, students can develop computational thinking by designing circuits, writing code, testing outputs, identifying errors, and improving their solutions through iterative processes. Among various physical computing platforms, Arduino has gained widespread popularity in educational settings because it is relatively affordable, open-source, flexible, and suitable for introducing students to programming and embedded systems concepts (Chung & Lou, 2021). Arduino-based learning activities have been shown to promote algorithmic thinking, creativity, problem-solving skills, and interdisciplinary learning within science, technology, engineering, and mathematics (STEM) education (Marín-Marín et al., 2024; Sarı et al., 2022).

Despite its educational potential, implementing Arduino-based practical activities in secondary schools remains challenging. Effective Arduino instruction requires access to hardware components such as microcontrollers, sensors, breadboards, LEDs, resistors, and connecting wires. However, many schools face limitations in equipment availability, laboratory facilities, maintenance costs, and instructional time. In large classes, students often share a limited number of Arduino kits, reducing opportunities for individual experimentation and repeated practice. Furthermore, novice learners frequently make wiring mistakes that can damage components or produce unexpected outcomes, leading teachers to limit practical activities and rely more heavily on theoretical instruction. Such constraints are problematic because meaningful learning in Informatics requires active engagement with designing, testing, debugging, and refining technological solutions (Rouse & Rouse, 2022).

To address these challenges, educational researchers have increasingly explored the use of virtual laboratories and simulation-based learning environments. Virtual laboratories allow students to conduct experiments, test hypotheses, and observe outcomes in simulated environments without the risks and costs associated with physical equipment. Research indicates that well-designed virtual laboratories can support conceptual understanding, procedural knowledge, and student engagement, particularly when access to physical resources is limited (Brinson, 2015; de Jong et al., 2013). Similarly, simulation-based learning environments can provide students with opportunities for repeated practice, immediate feedback, and self-paced exploration, all of which contribute to improved learning outcomes (Smetana & Bell, 2012). However, the effectiveness of virtual laboratories depends not only on the technology itself but also on the quality of instructional support provided to learners.

One simulation platform that has gained increasing attention in electronics and microcontroller education is Tinkercad Circuits. Developed as a web-based environment for circuit design and simulation, Tinkercad Circuits enables users to assemble electronic circuits, write Arduino code, run simulations, and observe system behavior in real time. Because it eliminates the risk of hardware damage and reduces the need for expensive equipment, Tinkercad Circuits offers an accessible alternative for introducing students to Arduino programming and circuit design (Supardi et al., 2022; Widiarini et al., 2021). Previous studies have reported that simulation platforms can facilitate students' understanding of electronics concepts and increase their confidence before engaging with physical hardware. Nevertheless, simply providing access to a simulation platform does not guarantee meaningful learning experiences. Students often require structured guidance to navigate simulation environments, connect theoretical concepts with practical tasks, and engage in systematic problem-solving activities.

Teaching modules can play a critical role in addressing this need for instructional guidance. Well-designed modules provide learners with clearly defined objectives, organized content, step-by-step procedures, practice activities, reflection opportunities, and assessment tasks. In technology-based learning environments, instructional modules can serve as scaffolding tools that help students progress from basic understanding to more complex applications. According to cognitive load theory, instructional materials should be designed to reduce unnecessary cognitive demands while supporting the acquisition of essential knowledge and skills (Sweller et al., 2019). Similarly, scaffolding theory suggests that structured instructional support can enable learners to accomplish tasks that would otherwise be beyond their current level of competence (Wood et al., 1976). Therefore, integrating Tinkercad Circuits within a carefully designed teaching module may enhance students' learning experiences by providing both technological access and pedagogical support.

Although previous studies have investigated Arduino-based learning, virtual laboratories, and simulation-supported instruction, relatively few studies have focused on developing and validating a comprehensive teaching module that integrates Tinkercad Circuits as the core platform for virtual Arduino practical work in secondary-level Informatics education. Existing research has generally emphasized the effectiveness of simulation tools or Arduino activities separately, with limited attention to the development of structured learning materials that guide students through learning objectives, circuit design, programming activities, troubleshooting procedures, and performance assessment. Consequently, there remains a need for instructional resources that combine pedagogically sound module design with accessible virtual simulation technology to support Arduino learning in resource-constrained educational settings.

Addressing this gap is particularly important for Grade XII Informatics education, where students are expected to demonstrate not only conceptual understanding but also practical competencies in programming, circuit design, and problem-solving. A structured Arduino–Tinkercad teaching module may provide an effective solution by enabling students to engage in safe, repeatable, and accessible virtual practical activities while supporting the achievement of curriculum learning outcomes. Therefore, this study aimed to develop and evaluate an Arduino teaching module integrated with Tinkercad Circuits for Grade XII Informatics learning using the Four-D (4D) Research and Development model. Specifically, the study sought to answer three research questions: (1) How valid is the Arduino–Tinkercad teaching module based on expert and practitioner evaluations? (2) How practical is the module according to teacher and student responses? and (3) How effective is the module in improving students' learning outcomes based on pretest–posttest performance and normalized gain scores? By addressing these questions, the study contributes to the growing body of research on virtual practicum resources and provides practical guidance for implementing Arduino learning in contexts where physical equipment is limited.

2. METHODS

2.1 Research Design

This study used a Research and Development design to produce and evaluate an Arduino teaching module integrated with Tinkercad Circuits. The development process followed the 4D model, consisting of define, design, develop, and disseminate stages (Thiagarajan et al., 1974). The feasibility of the module was evaluated through three indicators: validity, practicality, and initial effectiveness.

The initial effectiveness test used a one-group pretest-posttest pre-experimental design during the large-group trial. This design was selected because the study focused on obtaining preliminary evidence of learning improvement after students used the developed module. However, the design does not allow strong causal claims because it does not include a control group (Campbell & Stanley, 1963).

2.2 Participants

The study was conducted at SMA Negeri 4 Surabaya. Participants were selected purposively because they were directly involved in Grade XII Informatics learning and in the implementation of the Arduino–Tinkercad module. The participants consisted of two expert lecturers, two Informatics teachers, five Grade XII students in a small-group trial, and 33 Grade XII students in a large-group trial.

The expert lecturers and teachers evaluated the module through validation sheets. The teachers also provided practicality responses after reviewing or using the module in the learning context. The small-group trial involved five students to identify readability and usability issues before field testing. The large-group trial involved 33 students to obtain student practicality responses and initial effectiveness data.

Before data collection, the researcher obtained permission from the school and coordinated the research schedule with the Informatics teachers. The research activities were explained to participants, participation was voluntary, and students' identities were anonymized in the analysis and reporting.

2.3 Instruments

Three instruments were used to collect data: validation sheets, practicality questionnaires, and pretest-posttest instruments.

The validation sheet used a 1-5 rating scale and consisted of 13 indicators grouped into four aspects: content suitability, language, presentation, and graphics. The content aspect assessed the alignment of the module with learning outcomes, Arduino concepts, and virtual practicum activities. The language aspect assessed readability, terminology accuracy, and clarity of instructions. The presentation aspect assessed the sequence of learning activities, integration of theory and practice, and completeness of module components. The graphics aspect assessed layout, typography, and the quality of visual guidance.

The practicality questionnaires used a 1-5 Likert scale. The teacher questionnaire consisted of 25 indicators covering ease of use, feasibility of classroom implementation, clarity of Tinkercad procedures, suitability for learning, and overall implementation potential. The student questionnaire consisted of eight statements covering material clarity, simulation steps, display readability, and usefulness for learning.

The initial effectiveness instrument consisted of pretest and posttest items with a maximum score of 100. The test was designed to measure students' understanding of Arduino concepts, basic circuit logic, and code-related problem solving after using the module. The content validity of the test items was reviewed by validators to ensure alignment with the module objectives and Grade XII Informatics learning outcomes. Because item-level response data were not available in the manuscript file, internal consistency coefficients for the questionnaires could not be recalculated in this revision and should be added by the authors if the raw data are available.

2.4 Procedure

In the define stage, the researcher analysed learning needs, student characteristics, Arduino practicum constraints, and relevant Grade XII Informatics learning outcomes. This stage produced the specification of module requirements, including the need for virtual practicum guidance, structured exercises, and evaluation tasks.

In the design stage, the researcher prepared the module structure, learning sequence, Tinkercad Circuits practicum workflow, activity sheets, exercise scenarios, and assessment instruments. The module was designed to integrate learning objectives, brief theory, circuit simulation steps, coding tasks, troubleshooting prompts, summaries, and evaluations.

In the development stage, the module draft was reviewed by validators. Revisions were made based on validation results and qualitative suggestions. The revised module was then tested in a small group to identify readability and usability issues. After further revision, the module was implemented in the large-group trial to collect practicality and initial effectiveness data.

In the dissemination stage, dissemination was limited to the research school. The final version of the module was provided to the Informatics teachers for classroom use in the research context.

2.5 Data Analysis

Validity data were analysed using Aiken's V. Each indicator was scored by validators using a 1-5 scale. The V value was calculated for each indicator and then summarized by aspect and overall average. The categories used were highly valid (0.81-1.00), valid (0.61-0.80), moderately valid (0.41-0.60), less valid (0.21-0.40), and invalid (0.00-0.20) (Aiken, 1985).

Practicality data were analysed using mean and standard deviation. The practicality categories were very practical (4.21-5.00), practical (3.41-4.20), fairly practical (2.61-3.40), and impractical (1.00-2.60). For the large-group trial, the distribution of student response categories was also calculated using frequency and percentage.

Initial effectiveness was analysed using normalized gain (N-gain). N-gain was calculated by comparing students' pretest and posttest scores against the maximum score. The categories were high ($g >= 0.70$), moderate ($0.30 <= g < 0.70$), and low ($g < 0.30$) (Hake, 1998). Data were processed using Microsoft Excel to ensure consistent calculations for Aiken's V, mean, standard deviation, category distribution, and N-gain.

3. FINDINGS AND DISCUSSION

3.1 Findings

3.1.1 Product Development Results

The product developed in this study was an Arduino teaching module integrated with Tinkercad Circuits for Grade XII Informatics. The module consisted of five units that included learning objectives, core material, Tinkercad simulation guidance, circuit and coding exercises, summaries, and evaluation tasks. The practicum activities guided students to design circuits, write code, run simulations, observe outputs, and revise errors in a virtual environment.

3.1.2 Module Validity

The module was evaluated by four validators using Aiken's V. The overall average validity score was 0.861, which falls into the highly valid category. Twelve of the 13 indicators were categorized as highly valid, and one indicator was categorized as valid. The indicator scores ranged from 0.750 to 1.000.

Table 1. Recapitulation of teaching module validity (Aiken's V) per aspect

Aspect	Number of indicators	V average	V range	Category
Content suitability	4	0.844	0.750-0.938	Highly valid
Language	3	0.875	0.812-1.000	Highly valid
Presentation	3	0.854	0.812-0.938	Highly valid
Graphics	3	0.875	0.812-0.938	Highly valid
Total	13	0.861	0.750-1.000	Highly valid

These results show that the module met the expected validity criteria in terms of content, language, presentation, and graphics before it was used in student trials.

2.1.3 Module Practicality

The practicality of the module was assessed using teacher and student response questionnaires. Teacher responses produced an average score of 4.24, which was categorized as very practical. Student responses also showed very practical results, with an average score of 4.40 in the small-group trial and 4.47 in the large-group trial.

Table 2. Recapitulation of module practicality based on user responses

Respondents	n	Scale	Mean	SD	Category
Teachers	2	1-5	4.24	1.03	Very practical
Students, small group	5	1-5	4.40	0.22	Very practical
Students, large group	33	1-5	4.47	0.23	Very practical

In the large-group trial, 29 students (87.88%) rated the module as very practical, while four students (12.12%) rated it as practical. In the small-group trial, all students rated the module as very practical.

2.1.4 Initial Effectiveness

Initial effectiveness was measured using pretest and posttest scores in the large-group trial. The mean pretest score was 50.24 (SD = 8.11), while the mean posttest score was 75.33 (SD = 10.87). The minimum-maximum score range was 40-70 for the pretest and 55-95 for the posttest.

Table 3. Descriptive statistics of pretest and posttest scores (n = 33**)**

Statistics	Pretest	Posttest
Mean	50.24	75.33
SD	8.11	10.87
Minimum-maximum	40-70	55-95

The average N-gain was 0.520, which is categorized as moderate. Six students (18.18%) were in the high N-gain category, 23 students (69.70%) were in the moderate category, and four students (12.12%) were in the low category.

Table 4. Summary of N-gain categories (n = 33)

N-gain category	Range	f	%
High	g >= 0.70	6	18.18
Moderate	0.30 <= g < 0.70	23	69.70
Low	g < 0.30	4	12.12
Total	-	33	100.00

3.2 Discussion

The findings indicate that the Arduino teaching module integrated with Tinkercad Circuits has strong feasibility as a virtual practicum resource for Grade XII Informatics. The high Aiken's V score suggests that the module content, language, presentation, and graphics were considered appropriate by validators. This result is important because a virtual practicum module must not only present correct technical content but also provide clear procedural guidance for students who may still be novice learners in circuit design and Arduino programming.

The module may work because it combines three instructional elements: structured content, simulation-based practice, and guided evaluation. First, the module provides a gradual learning sequence from objectives and concepts to practice and assessment. Second, Tinkercad Circuits allows students to test circuits and code without the immediate risk of damaging physical components. Third, the module provides step-by-step tasks that reduce cognitive load and support students during initial practice. This structure is consistent with simulation-based learning literature, which emphasizes that virtual laboratories are more useful when students receive clear scaffolding rather than only access to a simulation tool (de Jong et al., 2013; Smetana & Bell, 2012).

The practicality results suggest that the module was easy to use in the research context. Teachers rated the module as very practical, and most students in the large-group trial also placed it in the very practical category. This finding indicates that the module has readable instructions, usable activity sequences, and learning tasks that students can follow. In the context of limited Arduino kits, the module can help teachers organize practical activities more efficiently because students can practise virtually before or alongside physical demonstrations. This is aligned with previous findings that virtual and remote laboratories can expand access to practical experiences when physical resources are limited (Brinson, 2015).

The initial effectiveness result was moderate. The improvement from pretest to posttest suggests that the module helped students improve their understanding of Arduino concepts and simulation-based practicum procedures. However, the moderate N-gain also indicates that the module may be more effective for strengthening basic conceptual and procedural understanding than for developing advanced skills. More complex outcomes, such as independent debugging, open-ended project design, and broader computational thinking, may require longer implementation, repeated practice cycles, and more specific performance-based assessment.

Compared with previous studies, this research supports the value of Arduino-related learning for computational thinking and problem solving, but it adds a product development contribution. Prior studies have often focused on Arduino as a learning tool or on virtual laboratories as alternative learning environments. This study positions Tinkercad Circuits as part of a structured teaching module that includes objectives, learning materials, practicum steps, exercises, and evaluation. The novelty, therefore, lies in the integration of module design and simulation-based Arduino practicum for secondary-level Informatics learning, followed by evaluation through validity, practicality, and initial effectiveness indicators.

Several alternative explanations should be considered. Because the effectiveness test used a one-group pretest-posttest design, the increase in scores cannot be attributed only to the module. Other factors, such as teacher explanation, students' familiarity with test items, peer assistance, or the novelty of using Tinkercad, may also have influenced the results. The practicality data were self-reported, so student responses may have been influenced by positive impressions of new technology or by the classroom situation during data collection. In addition, the large-group trial involved only one school, which limits the generalizability of the findings.

The study also has technical and pedagogical limitations. Tinkercad simulations cannot fully represent all physical conditions, such as loose connections, component tolerance, sensor noise, or component damage. Therefore, the module should be viewed as a support for initial practice and concept reinforcement, not as a complete replacement for physical Arduino practicum. When physical equipment is available, teachers should combine virtual simulation with hands-on activities so that students can also develop tactile and hardware troubleshooting skills.

Further development should focus on strengthening the module's impact on higher-level Informatics competencies. Future studies should use a quasi-experimental design with a comparison group, involve several schools, and include performance-based measures such as debugging rubrics, project assessment, and computational thinking instruments. The module can also be improved by adding reflection prompts, troubleshooting journals, and open-ended project tasks at the end of each unit. These additions may help students move beyond following procedures toward explaining, evaluating, and improving their own solutions.

4. CONCLUSION

This study developed and evaluated an Arduino teaching module integrated with Tinkercad Circuits to support virtual practicum activities in Grade XII Informatics learning. The findings demonstrated that the module achieved a high level of validity (Aiken's V = 0.861), was perceived as very practical by both teachers and students, and showed moderate initial effectiveness in improving students' learning outcomes, as indicated by the increase in pretest–posttest scores and an average N-gain of 0.520. These results suggest that the module can serve as a feasible instructional resource for providing safe, accessible, and repeatable Arduino learning experiences, particularly in contexts where physical equipment is limited. Nevertheless, several limitations should be acknowledged. The effectiveness evaluation employed a one-group pretest–posttest design without a comparison group, which restricts causal interpretation of the observed learning gains. In addition, the study was conducted in a single school with a relatively small sample, limiting the generalizability of the findings.

Furthermore, the module was evaluated primarily through cognitive learning outcomes and did not assess higher-order competencies such as debugging performance, project development, or computational thinking. Therefore, future research should employ quasi-experimental or experimental designs with larger and more diverse samples across multiple schools, incorporate performance-based assessments, and investigate the long-term impact of Arduino–Tinkercad learning modules on students' computational thinking, problem-solving abilities, and practical programming skills.

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Conflicts of Interest: The authors declare no conflict of interest.

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