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Integration of ethno-modelling and 3N: An innovative digital worksheet framework to enhance students' mathematical critical thinking skills

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Abstract

Technological developments require teachers to innovate, including the digitalization of Student Worksheets (LKPD) to facilitate joyful, meaningful learning for students. The urgency of this study stems from the need for flexible digital teaching tools (online and offline) and for easy access to information. This study aims to develop a Digital Worksheet model based on Ethno-Modelling and 3N (*Niteni*, *Nirokke*, *Nambahi*). This development research uses the 4D model (Define, Design, Develop, and Disseminate) and draws on subjects from two provinces (D.I. Yogyakarta and West Java) representing seven districts/cities. Small tests were given to 20 students from the Greater Bandung area and 25 students from the D.I. Yogyakarta province. Field tests were conducted with 179 students across seven schools in the D.I. Yogyakarta and West Java provinces. The results of the study indicate that the digital worksheet based on Ethno-Modelling and 3N developed is valid and can be used without revision, with a combined percentage of 93.33%. The results of a small test based on student responses (90.40%) indicate that the digital worksheet design based on Ethno-Modelling and 3N (EM3N) received strong responses, making it very practical to use. The results of the field test show that the achievement of mathematical critical thinking skills among students who learn using digital worksheets has a very large effect size, as measured by Cohen's d ($d > 0.80$). This finding provides a positive impact that digital worksheets designed based on the integration of ethno-modelling and 3N (EM3N) that align learning with the cultural context can strengthen curriculum concepts and enhance students' mathematical critical thinking skills.

Keywords:
Critical thinking, Deep learning, EM3N, Ethno-modelling, *Niteni*-*Nirokke*-*Nambahi*

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1. INTRODUCTION

Critical thinking is a higher-order thinking skill that involves logical, reasoned thinking focused on solving mathematical problems (Edwar et al., 2023; Hidayat et al., 2018; Payadnya et al., 2023; Trisnani et al., 2024). Thus, mathematical critical thinking is a systematic ability that can be used to solve mathematical problems by combining prior knowledge and mathematical reasoning. Mathematical thinking ability is still an international concern, as was done by PISA in 2022 by making this ability one of the main focuses in its survey (İdil et al., 2024; Kusmaryono & Kusumaningsih, 2023; Nurgabyl et al., 2023; Sistyawati et al., 2023; Wijaya et al., 2024). Furthermore, critical thinking skills are related to the five process skills (problem solving, reasoning, understanding, communication, connections, and representation) possessed by students (Hidayat & Aripin, 2019; Hidayat & Husnussalam, 2019; Hidayat et al., 2019; NCTM, 2000). Thus, students need highly developed mathematical critical thinking skills. This indicates that mathematical critical thinking skills remain important and a top priority in the development of mathematics learning.

However, the mathematical critical thinking skills of junior high school students in Indonesia remain relatively low. This is evident from preliminary studies conducted by several researchers, which indicate that these skills are still unsatisfactory (Hidayat & Sari, 2019; Sari & Hidayat, 2019). Furthermore, survey results from the PISA (Programme for International Student Assessment) have been less than encouraging. The results of the survey that was conducted show that in 2012, Indonesia was ranked 64th out of 65 countries with a score of 375 (Alfiani, 2021), in 2015 the PISA score was still below the international average score of 500 (Husain & Dewi, 2024), in 2018 it was ranked 74th out of 80 countries (Ismawati et al., 2023), and in 2022 the PISA score was 379 (Putrawangsa & Hasanah, 2022; Wijaya et al., 2024).

After the COVID-19 pandemic ended, schools re-implemented face-to-face learning, although online learning was still facilitated due to the impact of the new normal. This is in line with previous research findings that stated that even though the learning process had been carried out offline, educators still conducted online learning activities through the Google Classroom or Zoom platforms, because they were accustomed to teaching online (Irfan et al., 2020; Irfan et al., 2023; Pertiwi et al., 2021). The problem is that online learning that has been implemented so far is hampered by the unequal distribution of internet access in Indonesia, the inability of parents to provide adequate online learning facilities, such as data quotas and smartphones, learning devices that do not facilitate online learning, and learning loss due to teachers' inability to assess and differentiate between competent and incompetent students (Hung & Chou, 2015; Irfan et al., 2020; Rohaeti et al., 2023; Smart & Cappel, 2006). Although it has been recognized that the COVID-19 pandemic has had positive effects, such as improving teachers' digital literacy skills, teachers are beginning to recognize and apply blended learning, or learning that combines online and offline learning, and learning tools, including teaching materials, have begun to shift from hardcopy to softcopy (Widodo et al., 2023).

The use of the internet and multimedia technology has revolutionized the delivery of knowledge and can serve as an alternative to traditional classroom learning (Alzubi, 2023; Fu, 2022). Online learning has its own strengths, challenges, and obstacles, requiring every element of education to facilitate active learning (Greenhow et al., 2022; Latifah et al., 2024; Maatuk et al., 2022). However, in practice, teachers are unable to assess and differentiate between competent and incompetent students, and a decline in students' cognitive abilities is emerging (Desti et al., 2020; Kurniansyah et al., 2022). Therefore, online mathematics learning should be combined with offline learning, in other words, learning should be conducted in a blended manner (Latif et al., 2024). Furthermore, learning tools, such as teaching materials, must be adapted to the conditions of students who are already too familiar with smartphones (Hidayat et al., 2023). Therefore, mathematics learning tools are necessary to support tailored blended mathematics learning aligned with learning objectives.

One tool that can be prepared for mathematics learning is the electronic Student Worksheet (e-LKPD). E-LKPD, a digital worksheet, is used by teachers to increase student engagement in the learning process (Esen et al., 2023; Hidayat & Aripin, 2023; Ramlah et al., 2023). The benefits of using digital teaching materials include making it easier for educators to manage the learning process, helping educators direct their students to discover concepts through their activities, to develop process skills and develop scientific attitudes, and helping educators monitor students' success in achieving learning goals (Harisman et al., 2023; Hendriana et al., 2019; Kurniansyah et al., 2022; Pertiwi et al., 2021; Purnomo et al., 2024; Rohaeti et al., 2023; Rohaeti et al., 2019).

A preliminary study found that 40 studies on student worksheets (LKPD) and meta-analyses yielded an effect size of 1.281 (Widodo et al., 2023). This finding aligns with other studies that suggest that e-LKPD used in mathematics learning can improve critical thinking skills (Latifah et al., 2024; Roswahyuliani et al., 2024; Saig & Hershkovitz, 2024; Suroyaningsih et al., 2024; Utaminingsih et al., 2024; Widodo et al., 2024). These findings indicate that LKPD has a significant and positive impact on students' cognitive abilities. Therefore, LKPD needs to be developed and tailored to students' characteristics to make mathematics learning more meaningful and to improve students' critical mathematical thinking skills.

Currently, the school curriculum requires project-based learning for every subject. This aligns with the Indonesian Ministry of Primary and Secondary Education's deep learning program, which mandates that teachers create meaningful, applicable learning experiences to foster a deeper understanding of concepts (rather than simply memorizing them). Furthermore, classroom learning should be enjoyable (joyful learning), and the material delivered through learning technology should be meaningful (meaningful learning) for student comprehension. Project-based learning allows teachers flexibility and freedom to design learning projects that are relevant and relevant to the school environment. Therefore, mathematics learning projects tailored to the characteristics of the environment, customs, or culture surrounding students can be used as an alternative to project-based learning in mathematics (Nasution et al., 2021). The problem so far is that project-based learning in mathematics has not yet incorporated cultural concepts, even though the use of cultural contexts makes mathematics learning more meaningful for students (Cervantes-Barraza & Araujo, 2023; Hortelano & Lapinid, 2024; Nurcahyo et al., 2024; Prahmana, 2022; Prahmana et al., 2023; Risdiyanti & Prahmana, 2021; Sa'diyah et al., 2024; Sudirman et al., 2024; Supriadi & Hanif, 2024; Utami et al., 2022). Therefore, it is necessary to develop student worksheets tailored to students' environments, leveraging the cultural context to make mathematics learning more meaningful and enjoyable. One cultural context that can be used is the ketupat festival (Eid al-Ketupat) in the northern coastal areas of Java for learning linear programming (Utami et al., 2022).

Besides ethnomathematics, one of the learning models for mathematics is 3N. The 3N Learning Model (*Niteni*, *Nirokke*, *Nambahi*) is one of the learning models originating from the Tamansiswa teachings and used by Ki Hadjar Dewantara in the learning process (Astuti et al., 2023; Kusumaningrum et al., 2024; Latifah et al., 2024; Suroyaningsih et al., 2024; Widodo et al., 2024). As the name suggests, the learning stages using 3N are adjusted to its acronym, namely *Niteni*, *Nirokke*, and *Nambahi* (Astuti et al., 2023; Wijayanti et al., 2022). *Niteni* is an activity of marking that involves paying close attention and using all senses (Latifah et al., 2024; Suroyaningsih et al., 2024; Widodo et al., 2024). *Nirokke* is an activity of imitating what is taught through models/examples/models from teachers/learning resources by involving the mind, senses, feelings/conscience, and spirituality in an integral and harmonious manner (Latifah et al., 2024; Suroyaningsih et al., 2024; Widodo et al., 2024). *Nambahi* is the process of adding or subtracting what has been learned to develop creativity and ideas by utilizing learning resources (Latifah et al., 2024; Suroyaningsih et al., 2024; Widodo et al., 2024). 3N studies have shown that this learning model is effective for language learning (Ermawati & Rochmiyati, 2020; Rochmiyati & Putro, 2020). There has been little research linking 3N to mathematics learning, particularly integrating 3N concepts into learning tools.

In this regard, it is deemed necessary to develop teaching materials in the form of digital worksheets compiled using the 3N stages and having cultural characteristics modeled in contextual learning (ethno-modelling). This aligns with previous research indicating that LKPD use may affect students' cognitive abilities (Hendriana et al., 2019; Nurlaily et al., 2021; Sofiyan et al., 2020; Sutarni et al., 2024). The differences between their research and this study include the application of the ethno-modelling and 3N concepts (*Niteni*, *Nirokke*, *Nambahi*) in deep learning to improve students' mathematical critical thinking skills. This is what makes this current study new compared to previous research conducted by Hendriana et al. (2019), Nurlaily et al. (2021), Sofiyan et al. (2020), and Sutarni et al. (2024). Another difference is that the mathematical elements developed in this study are number elements, which results in a focus on these elements in digital worksheet development. Furthermore, the results of the digital worksheet development can be used for junior high school students for three years, namely grades VII, VIII, and IX. Thus, the problem to be solved in this study is how to develop digital worksheets based on ethno-modelling and 3N in deep learning to improve students' mathematical critical thinking skills.

2. METHOD

The method used in this study is development research, as described by Thiagarajan et al. (1974), which refers to the 4D model (Define, Design, Develop, and Disseminate). This is because the main objective of this study is the existence of research products (Sugiyono, 2016). The product obtained in this study is a digital worksheet based on ethno-modelling and 3N (EM3N) for deep learning to improve students' mathematical critical thinking skills. The development research process carried out with this model is presented in Figure 1.

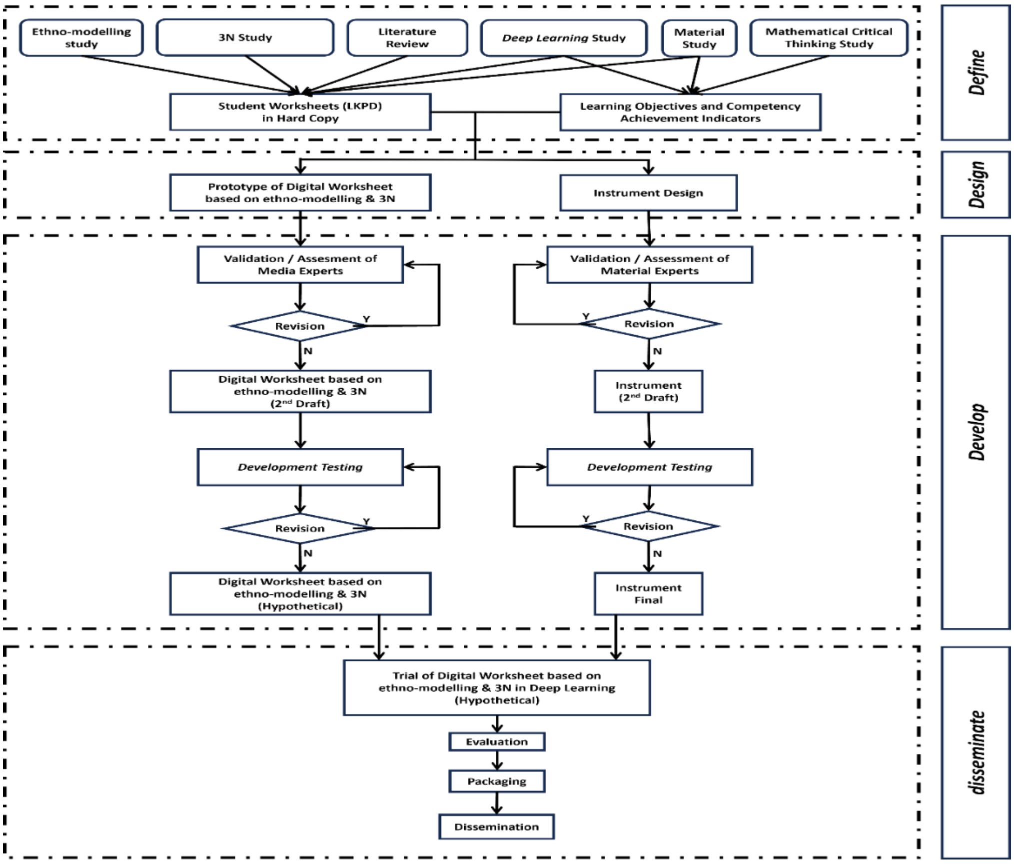

Figure 1. Research stages

Define Stage

The define stage aims to establish and define the development requirements. In principle, this stage is a preliminary study that does not attempt to test the hypothesis but rather to obtain information on the variables to be studied. In this define stage, a preliminary study was conducted on Ethno-Modelling, 3N (*Niteni*, *Nirokke*, *Nambahi*), deep learning, learning materials, and mathematical critical thinking skills, as well as other supporting literature deemed necessary as a source of support for the development of digital worksheets based on the EM3N integration model. All these design stages are expected to result in the formulation of specific competencies that students must achieve, especially mathematical critical thinking skills in number elements, through EM3N-based digital worksheets in deep learning.

Design Stage

The design stage aims to design an EM3N-based digital worksheet on number elements. Activities at this stage consist of three steps as follows: 1) Media Strategy, namely designing a digital worksheet platform to facilitate the research process carried out, so that the research objectives that have been set can be realized well. In this product created at least integrates the diagnostic process of students' initial mathematical abilities with EM3N-based digital worksheets in deep learning to measure critical thinking skills; 2) Evaluation, namely evaluating the equipment and conditions of needs required by students to achieve learning competencies that are in accordance with expectations; and 3) Sources, namely finding and determining learning sources that can support the creation of an EM3N-based digital worksheet platform. In addition to the EM3N-based digital worksheet prototype, other instruments for this study have been prepared, namely, product validation and student and teacher response sheets.

Develop Stage

The development phase aims to obtain a) a suitable and effective learning design; and b) the instruments required for this study. These two products through expert validation and developmental testing (Thiagarajan et al., 1974). During expert validation, experts assessed the EM3N-based digital worksheets developed and the instrument design for this study.

Expert validation was conducted by three lecturers with media expertise and three subject matter experts. User validation was done with mathematics teachers, while audience validation was conducted with students. The validation criteria included: a) Subject matter expert assessment, which reviewed material relevance, organization, evaluation, and practice questions, language, impact on learning strategies, and visual display. b) Media expert assessment, which considered language, impact on learning strategies, software engineering, and visual display. c) User assessment, which involved checks on material relevance, organization, evaluation, and practice questions, language, impact on learning strategies, and visual display. d) Audience assessment, conducted through a student response questionnaire, measured language, impact on learning strategies, and visual appearance. This phase used content validity testing via the Aiken method (Aiken, 1980, 1999). Content validity shows how well the assessment instrument covers the relevant constructs for specific objectives (Almanasreh et al., 2019).

The development step also tests the practicality of the EM3N-based digital worksheet. The research design used is a one-shot case study (Creswell, 2012). The worksheet is effective if the average score is above 70 (on a 100-point scale). This validation aims to gather input for revising the EM3N-based digital worksheet platform to assess feasibility.

In addition, three expert lecturers in Mathematics Education validated the research instrument, a mathematical critical thinking ability test. The team designed a test of mathematical critical thinking with five open-ended essay questions. The questions follow the critical thinking ability indicators defined by Facione (2011): interpretation, analysis, evaluation, inference, and explanation.

Disseminate Stage

In the disseminate stage, evaluation and packaging are included (Thiagarajan et al., 1974). The evaluation stage is conducted to determine the effect of product development on students' mathematical critical thinking skills. Packaging is carried out after going through improvements from the evaluation stage. This packaging involves distributing the product to partner schools. The data analysis technique used is multivariate analysis to determine the effect of the EM3N-based digital worksheet, with the covariate being students' initial mathematical abilities.

The research subjects included junior high schools in two regions: Greater Bandung (West Java Province) and D.I. Yogyakarta. The sample was selected purposively based on the availability of schools willing to participate and regional representation. Small tests were conducted on 20 students from the Greater Bandung area and 25 students from the D.I. Yogyakarta province. Meanwhile, the field tests stage was conducted on 179 students with the distribution of research in Greater Bandung consisting of four schools, namely one SMP in West Bandung Regency involving 20 students, one SMP in Cimahi City with 32 students, one SMP in Bandung City with 20 students, and one SMP in Bandung Regency with 30 students. Meanwhile, the sample from D.I. Yogyakarta consisted of three schools: one SMP in Yogyakarta City with 25 students, one SMP in Bantul Regency with 29 students, and one SMP in Kulon Progo Regency with 23 students.

The data analysis technique was carried out in several stages. First, a Shapiro-Wilk normality test was conducted to ensure that the data distribution met the assumptions of parametric statistics (Ghasemi & Zahediasl, 2012). Second, a paired-samples t-test was used to determine the significance of the difference between pre-test and post-test scores within each school (Cohen et al., 2002). To determine the magnitude of the EM3N-based digital worksheet's influence on students' mathematical critical thinking skills, the analysis was complemented by calculating effect sizes. The effect size was calculated using Cohen's *d* for paired samples (Cohen, 2013). Table 1 presents the interpretation of the d value according to Cohen's (2013) criteria.

Table 1. Interpretation of the Cohen's *d* value

Interval of *d* value	Interpretation
$0.20 \leq d < 0.50$	small effect
$0.50 \leq d < 0.80$	medium effect
$d \geq 0.80$	large effect

3. RESULTS AND DISCUSSION

3.1. Results

The resulting development research is a digital worksheet based on EM3N in deep learning to improve students' mathematical critical thinking skills. The creation of this digital worksheet involves several supporting applications, including Canva, YouTube, and Live Worksheet. The results of each 4D stage as a development research model are presented as follows.

3.1.1. Define Stage

The define stage, aimed at establishing development requirements to enhance students' mathematical abilities. Data shows that creating e-LKPD with a scientific approach can improve mathematical skills. A preliminary survey indicated that 83% of students struggled to understand the material during online learning, underscoring the need for supplemental electronic teaching materials. Further, an analysis of 40 relevant studies found an effect size of 1.281 for LKPD, demonstrating that Student Worksheets have a positive impact. These findings underscore the need to develop digital student worksheets combining cultural philosophy and modern education to improve students' mathematical critical thinking.

3.1.2. Design Stage

The design phase aims to design a digital worksheet based on ethno-modelling and 3N for number elements. Activities at this stage consist of three steps as follows: 1) Media strategy, 2) Evaluation, and 3) Resources. This design phase produces a prototype digital worksheet based on ethno-modelling and 3N for number elements. The appearance of the digital worksheet at the design stage is shown in Figure 2.

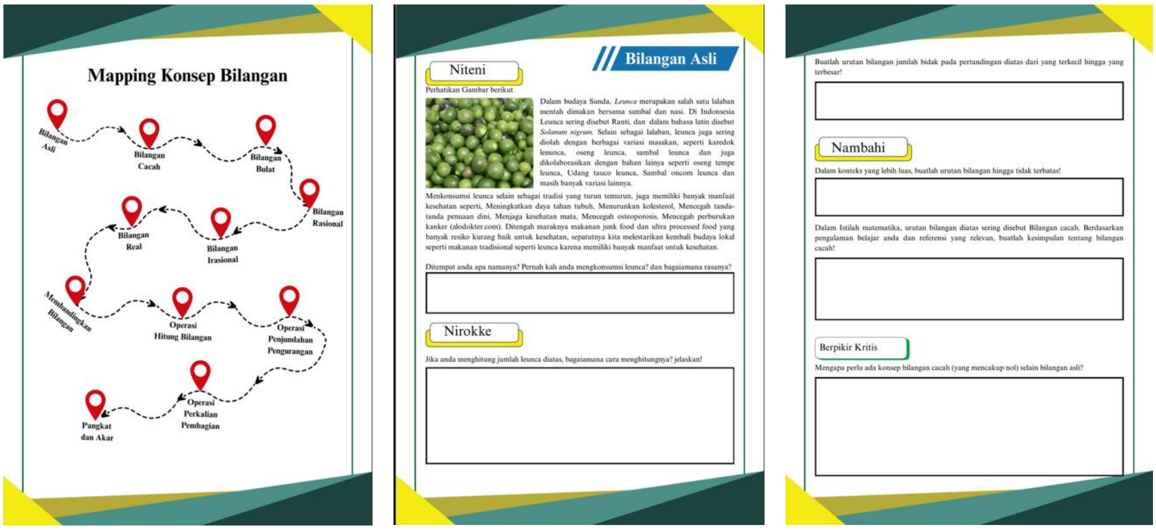

Figure 2. EM3N based digital worksheet display

3.1.3. Develop Stage

In accordance with the development research stages, expert appraisal (expert validation) and development testing (small test) were carried out. Expert appraisal is one of the worksheet product assessment activities conducted by individuals considered experts in the field of mathematics education. The expert appraisal was carried out on two research products, namely (1) EM3N-based Digital Worksheets, and (2) Students' Mathematical Critical Thinking Ability Tests.

The expert appraisal of the EM3N-based Digital Worksheets was conducted by six individuals considered experts in the field of mathematics education. Their expertise is demonstrated by their doctoral (or equivalent) academic background in mathematics education. The six people who assessed the research product in the form of EM3N-based Digital Worksheets, consisting of media experts and material experts, are as follows: a) Media Experts: (1) Dr. Muhammad Irfan, S.Si., M.Si. from Universitas Negeri Yogyakarta, (2) Naufal Ishartono, Ph.D. from Universitas Muhammadiyah Surakarta, and (3) Krisna Satrio Perbowo, Ph.D from Universitas Muhammadiyah Prof. Dr. Hamka; b) Material Experts: (1) Prof. Dr. Samsul Maarif, M.Pd. from Universitas Muhammadiyah Prof. Dr. Hamka, (2) Dr. Cecep Anwar Hadi Firdos Santosa, M.Si from Universitas Sultan Ageng Tirtayasa, and (3) Dr. Wasilatul Murtafiah, M.Pd. from Universitas PGRI Madiun.

In addition to the expert appraisals that assessed the digital worksheets containing media and materials, expert appraisals were also conducted on students' mathematical critical thinking ability tests undertaken by three people considered experts in the field of mathematics education, namely: (1) Prof. Dr. Rully Charitas Indra Prahmana, M.Pd. from Universitas Ahmad Dahlan, (2) Prof. Dr. Ibrahim, M.Pd. from UIN Sunan Kalijaga, and (3) Dr. Nelly Fitriani, M.Pd. from IKIP Siliwangi.

They validated the research product based on its content, often referred to as content validity. This validity provides evidence of the extent to which the elements of the assessment instrument are relevant and represent the targeted constructs for specific assessment purposes. The assessment aspects in the EM3N-based digital worksheet validation sheet were adapted from the assessment instrument for the Mathematics and Natural Sciences (MIPA) interest group textbook: (a) content feasibility, (b) legal feasibility, (c) presentation feasibility, and (d) language feasibility. Scoring on the validation sheet generally uses a Likert scale from 1 to 5, except for the legal and legislative feasibility aspect, the assessment uses a maximum score (10) or a minimum score (1).

The content validity index for Ethno-Modelling and 3N-based digital worksheet products can be determined using the Aiken method. To determine the suitability of a product (in this case, a worksheet), the content validity index (V) obtained from the calculation is compared with Aiken's V Table for N = 9 at a significance level of 5%. Based on the Aiken V Table, it was found that for N = 9 with five answer choices and a significance level of 5%, the value was 0.72. The results of the Aiken V calculation showed that for each assessment aspect for the 18 items on the worksheet assessment instrument, the content validity index (V) was more than 0.72 (see Table 2). In relation to these results, the worksheet was declared very good in terms of content, legal and legislative feasibility, presentation, and language. Additionally, these results suggest that the developed worksheet can be utilized in the next stage.

Table 2. Validity results of the content of EM3N-based digital worksheets

Indicator	Item No	Aiken V-Value	Description
Content	1	0.958	Valid
	2	0.931	Valid
	3	0.917	Valid
	4	0.944	Valid
Legal and legislative	5	1.000	Valid
	6	1.000	Valid
Presentation	7	0.931	Valid
	8	0.931	Valid
	9	0.944	Valid
	10	0.917	Valid
	11	0.889	Valid
	12	0.917	Valid
Language	13	0.931	Valid
	14	0.903	Valid
	15	0.944	Valid
	16	0.917	Valid
	17	0.931	Valid
	18	0.889	Valid

The content validity index for the student's mathematical critical thinking ability test can be calculated by averaging each aspect. The assessment aspects on the validation sheet for the student's mathematical critical thinking ability test are (a) the feasibility of the content, (b) the feasibility of the construction, and (c) the language aspect. The scoring of this validation sheet generally uses a scale of 1 (poor) to 4 (very good). To determine whether a product (in this case, a worksheet) is good or not, the average obtained for each aspect is at least 2.8 (on a scale of 4.0). The calculation results show that for each aspect of the assessment in the student's mathematical critical thinking ability test, the average is more than 3.33 (see Table 3). In relation to these results, the student's mathematical critical thinking ability test instrument is declared very good in terms of content, construction, and language. In addition, these results also indicate that the developed student mathematical critical thinking ability test instrument can be used for the next stage.

Table 3. The results of the validity of the content of the students' mathematical critical thinking ability

Indicator	Item No	Average	Description
Content	1	3.67	Valid
	2	3.67	Valid
	3	3.67	Valid
	4	4.00	Valid
Construction	5	4.00	Valid
	6	3.67	Valid
	7	3.33	Valid
Language	8	3.67	Valid
	9	4.00	Valid
	10	4.00	Valid
	11	4.00	Valid

In addition to expert appraisal, developmental testing was also conducted at the development stage. This activity aimed to test the practicability of the EM3N-based Digital Worksheet that had been developed. The research design used in development testing was a one-shot case study involving 45 junior high school students, divided into 20 in the Greater Bandung area and 25 in the D.I. Yogyakarta. The 45 students were selected purposively for involvement. In this activity, students in mathematics learning were given learning using the Digital Worksheet based on ethno-modelling and 3N. Next, they responded to the worksheet that had been used. Student responses in this test referred to indicators of worksheet appearance, material presentation, student appeal, product usefulness, and the potential to encourage critical thinking skills. The results of these student responses are presented in Table 4. Scoring of the practicability sheet used a Likert scale guideline from 1 (very poor) to 5 (very good). Data analysis for the practicability sheet used a comparison between the total score obtained and the ideal maximum score.

Table 4. Small test results based on student responses

No	Assessment Aspect	Percentage by School (%)							Average
		1	**2**	**3**	**4**	**5**	**6**	**7**	
1	Appearance	92	94	90	90	90	94	92	91.71
2	Material Presentation	90	92	90	92	90	90	90	90.57
3	Student Appeal	92	92	90	90	90	90	90	90.57
4	Benefits	90	90	90	90	90	90	92	90.29
5	Potential for enhancing cognitive abilities	90	90	90	88	88	88	88	88.86
	Average	**90.8**	**91.6**	**90**	**90**	**89.6**	**90.4**	**90.4**	**90.40**

3.1.4. Disseminate Stage

The disseminate phase includes validation testing, packaging, and dissemination. Validation testing is conducted to implement the EM3N-based digital worksheets with actual users, often referred to as a field test. The disseminate phase uses a quasi-experimental design with a one-group pretest–posttest model. This design was chosen because it is suitable for testing the effectiveness of a learning product without involving a control group and for comparing student learning outcomes before and after treatment. The treatment in question is the implementation of EM3N-based digital worksheets in mathematics learning.

The results of this study present empirical findings related to the implementation of EM3N-based digital worksheets in mathematics learning. The analysis focuses on the effectiveness of this digital innovation in improving students' mathematical critical thinking skills through trials in seven secondary schools in two different regions: Greater Bandung and D.I. Yogyakarta.

Before the analysis to test the effectiveness of the EM3N-based digital worksheets, prerequisite tests were first conducted. One of the prerequisite tests used was the normality test (see Table 5).

Table 5. Normality test of pre-test and post-test data

Class	Pre-test			Post-test		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Experimental Class 1	0.959	32	0.254	0.939	32	0.070
Experimental Class 2	0.928	20	0.140	0.941	20	0.253
Experimental Class 3	0.955	30	0.226	0.960	30	0.307
Experimental Class 4	0.966	20	0.677	0.938	20	0.220
Experimental Class 5	0.940	25	0.148	0.942	25	0.160
Experimental Class 6	0.944	23	0.216	0.968	23	0.635
Experimental Class 7	0.934	29	0.071	0.935	29	0.076

Based on the results of the Shapiro–Wilk normality test, all experimental classes in both pre-test and post-test data obtained significance values greater than 0.05. This indicates that the data distribution in each class does not differ significantly from the normal distribution, so the assumption of normality is met. In the Greater Bandung area (Experiments 1–4), both pre-test and post-test data showed significance values ranging from 0.071 to 0.677, all above the 0.05 limit. Similarly, in the Yogyakarta area (Experiments 5–7), significance values ranged from 0.070 to 0.635, also exceeding 0.05. These findings indicate that the data from both regions have a reasonable and representative distribution. Thus, the data is suitable for analysis using parametric statistical tests, so the next stage of analysis is a paired t-test to evaluate the effectiveness of EM3N-based digital worksheets in improving students' mathematical critical thinking skills in two different regional contexts (see Table 6).

Table 6. Paired sample t-test

			t	df	Sig. (2-tailed)
Greater Bandung	Pair 1	Postest1 - Pretest1	22.258	31	0.000
	Pair 2	Postest2 - Pretest2	8.776	19	0.000
	Pair 3	Postest3 - Pretest3	14.119	29	0.000
	Pair 4	Postest4 - Pretest4	9.702	19	0.000
D.I. Yogyakarta	Pair 5	Postest5 - Pretest5	12.780	24	0.000
	Pair 6	Postest6 - Pretest6	18.191	22	0.000
	Pair 7	Postest7 - Pretest7	16.574	28	0.000

Table 6 shows that in all experimental classes, both in the Greater Bandung area (Experiments 1–4) and in the D.I. Yogyakarta (Experiments 5–7), the significance value obtained was less than 0.05 (Sig. < 0.05). This confirms that there is a significant difference between the pre-test and post-test scores in each class. Thus, the use of EM3N-based digital worksheets has been proven to improve student learning outcomes. The high t-values in all pairs, especially in Experiment 1 (t = 22.258) and Experiment 6 (t = 18.191), strengthens the evidence that the learning intervention through EM3N-based digital worksheets is efficacious in improving students' mathematical critical thinking skills. In general, these results are consistent across both regions, so it can be concluded that EM3N-based digital worksheets have a significant effect on improving students' mathematical critical thinking skills, even when applied in school contexts in different regions. After a paired sample t-test revealed a significant difference between the pre-test and post-test results in each experimental class, the next step was to calculate the effect size (see Table 7). This analysis aimed to determine the extent to which the implementation of EM3N-based digital worksheets significantly improved students' critical mathematical thinking skills. The effect size was calculated using Cohen's *d* for paired samples, allowing for both statistical significance and practical significance of the intervention.

Table 7. Cohen's *d* value results for paired samples

Area	Class	n	t	Cohen's *d*	Interpretation
Greater Bandung	Experimental Class 1	32	22.258	3.94	Very large
	Experimental Class 2	20	8.776	1.96	Very large
	Experimental Class 3	30	14.119	2.58	Very large
	Experimental Class 4	20	9.702	2.17	Very large

Area	Class	n	t	Cohen's *d*	Interpretation
D.I. Yogyakarta	Experimental Class 5	25	12.780	2.56	Very large
	Experimental Class 6	23	18.191	3.79	Very large
	Experimental Class 7	29	16.574	3.08	Very large
	Average			**2.87**	**Very large**

The results of the effect size calculation using Cohen's *d* (see Table 7) show that all experimental classes, both in the Greater Bandung area and the D.I. Yogyakarta, have a huge effect size (d > 0.80). Cohen's *d* values ranged from 1.96 to 3.94, with an overall average of 2.87. This indicates that the implementation of EM3N-based digital worksheets not only provides statistically significant improvements but also has a huge practical impact on students' mathematical critical thinking skills. This finding confirms that the learning model using EM3N-based digital worksheets developed has high effectiveness in the learning contexts in two different regions.

3.2. Discussion

The findings of this EM3N-based digital worksheet development study indicate an improvement in students' critical mathematical thinking skills. Furthermore, the interaction between learning resources and students, including learning through digital worksheets, can increase student interest in learning.

This EM3N-based digital worksheet also utilizes other applications in its development, such as CANVA, YouTube, and Live Worksheets. This is expected to facilitate students and teachers in conducting online learning, including worksheets, attendance lists, and learning evaluations that parents can access. The digital worksheets created summaries material on number elements, which can help students improve their critical mathematical thinking skills (Kurniansyah et al., 2022; Pertiwi et al., 2021).

These digital worksheets were developed in stages to produce a product suitable for use in the learning process. Several needs analyses were conducted in the first stage of product development, including theoretical studies on ethno-modelling, the 3N (*Niteni*, *Nirokke*, *Nambahi*), deep learning, and curriculum studies on user needs. These were determined during initial observations. The following analysis was conducted to determine the theme and scope of the limited digital worksheets developed (Hidayat et al., 2022; Hidayat et al., 2023).

In the design stage, sketches of the digital worksheet content were completed, considering student characteristics. Next, a flowchart, storyboard, and user interface were created. This flowchart was created to provide a high-level overview of the flow or progression of the digital worksheet product as a learning medium from one slide to the next. The storyboard was used to describe each slide, including the display of images and other related information (Herbst et al., 2014; Hidayat et al., 2023; Jones, 2008; Webel & Conner, 2017).

The development stage went through several revisions based on the guidance and input of validators before becoming complete product design. Based on the testing results, the digital worksheet product design underwent refinements to produce a product ready for testing. During the development stage, researchers created the necessary learning media elements, such as text, images, videos, and materials, into a complete, ready-to-use medium. Once the product was finished, it was validated by experts, including material experts and media experts. The validation process was conducted because it could help refine the developed digital worksheet (Hidayat et al., 2023). During the development stage, small test was also conducted to gather suggestions and feedback from users, ensuring the EM3N-based digital worksheet was better prepared for dissemination (see Figure 3).

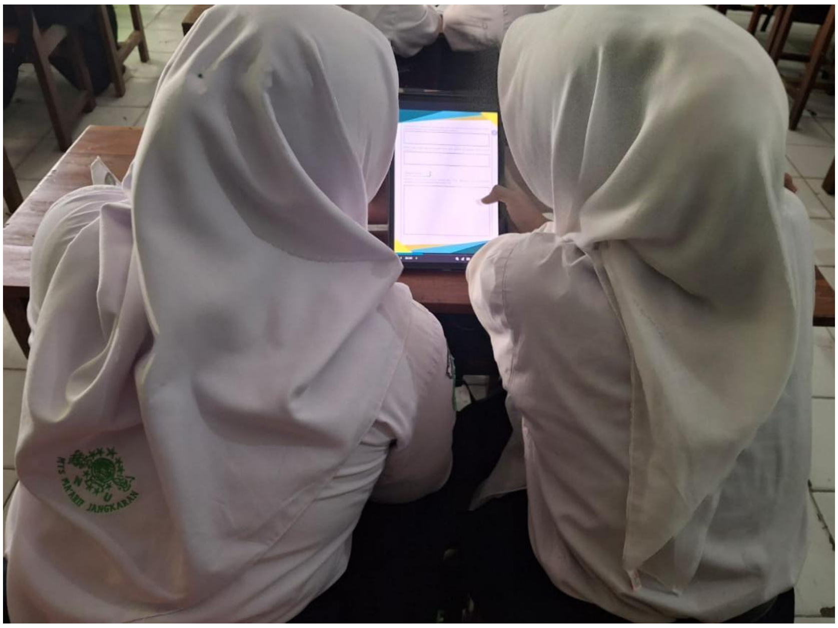

Figure 3. Small test of EM3N-based digital worksheets by students

The disseminate phase is a full-fledged learning experiment. At this stage, it was clear that students learning with EM3N-based digital worksheets began to develop improved mathematical critical thinking skills. One of the most significant reasons for this was the increased flexibility of the learning process. Students could study the material whenever and wherever they wanted. Students could also study the material thoroughly and freely choose areas of the material they felt they lacked understanding. This aligns with Kurniansyah et al.'s (2022) findings that engaging and interactive learning media can increase student learning motivation.

The results of the disseminate phase indicate that the development of EM3N-based digital worksheets significantly contributed to students' achievement of mathematical critical thinking skills. Furthermore, diverse cultural experiences can provide valuable information for students to develop a better understanding of critical thinking.

This study on EM3N-based digital worksheets was conducted in schools with diverse cultural and regional contexts. This condition aligns with Vygotsky's (1978) theory of social constructivism, which emphasizes that knowledge is constructed through social interactions within a cultural context. Through ethno-modelling, students learn to connect mathematical concepts with local cultural practices, while the 3N stages (*Niteni*, *Nirokke*, *Nambahi*) facilitate a gradual learning process, from observing, imitating, to developing concepts. More active student engagement was also reflected in interviews with students from schools in the Greater Bandung area.

Researcher : What do you think about learning with this digital worksheet?
Student : It is more interesting because it includes examples of traditional houses. So it is not just numbers but also relates to everyday life.
Researcher : Does the cultural context make it easier for you to understand the material?
Student : Yes, I understand better why the formulas or concepts are used. So, it is not just about calculations.

A teacher in D.I. Yogyakarta also added that changes in students' learning attitudes were clearly visible during the learning process.

Researcher : Are students more active with these digital worksheets?
Teacher : That is right. They ask questions more often, discuss things, and even try to find examples of other cultures beyond those on the digital worksheets. This shows that they are now more critical and motivated.

Regarding the effect size calculation, Cohen's *d* showed a value greater than 0.80 in all experimental classes. This indicates that the difference in scores is not only statistically significant but also practically meaningful. This shows that learning with EM3N-based digital worksheets does have a substantial impact on students' mathematical critical thinking skills. This finding supports the research of Rosa and Orey (2021), which confirmed that ethno-modelling can bridge formal mathematics with cultural practices. Similarly, Daryati et al. (2024) suggested that local wisdom-based worksheets can significantly increase student engagement and learning outcomes.

The 3N approach (*Niteni*, *Nirokke*, *Nambahi*) has been shown to provide a profound learning experience. This aligns with Bandura's (1971) social learning theory, which suggests that in the teaching-learning process, the interaction of observation, imitation, and development should be emphasised.

The conceptual synergy of the EM3N-based digital worksheets in this study is presented in Table 8.

Table 8. Conceptual synergy of EM3N-based digital worksheets

Stage 3N (Ki Hadjar Dewantara's Philosophy)	Ethno-Modelling Cycle (Pedagogical Action)	Deep Learning Focus	Mathematical Critical Thinking Ability Indicators
Niteni (Observe)	Introduction to cultural context and identification of ethnomathematical problems	Consciousness and contextualization	Formulate the main points of the problem, and reveal the facts in the problem
Nirokke (Imitate)	Translating cultural problems into academic mathematical models	Application of essential and applicable knowledge	Selecting logical arguments in solving problems, and inferences/conclusions temporarily
Nambahi (Adding/Innovating)	Model modification, critical reflection, and creation of new variations	Reflection and self-regulation	Detecting bias with different points of view, and drawing conclusions (Inference)

Table 8 shows that, in the context of developing mathematical critical thinking skills, *Niteni* functions as a reality filter. Students must identify hidden mathematical elements. *Niteni* requires students to search for and filter facts from a complex cultural context. Therefore, the outcome of this stage is students' ability to formulate key issues and uncover the facts contained in the problem based on their empirical observations (Darmayasa, 2019; Nurcahyo et al., 2024; Rodríguez-Nieto et al., 2025; Umbara et al., 2023).

Activities in the *Nirokke* stage (see Table 8) align with the application dimension of deep learning. In terms of developing mathematical critical thinking skills, *Nirokke* is the reasoning development phase. Students must select logical arguments—that is, choose the most appropriate mathematical concepts to validate their models. This process ensures that model application is not merely mechanical but based on conceptual understanding that supports tentative inferences (Rosa & Orey, 2021).

The improvement in critical mathematical thinking skills that occurs at the *Nambahi* stage is that students can detect bias from different perspectives (see Table 8). Students are required to reflect on the validity of their academic models compared to indigenous cultural practices (ethnomathematical reality). The ability to detect bias emerges when students try to compare the effectiveness of modified models with the original model (English & Halford, 2012; Rosa & Orey, 2021). Furthermore, this stage also encourages students to be able to draw critical conclusions. Thus, students can construct mature inferences, based on evaluation and modification of models that have been enriched with variations. The models' students produce are not just solutions but also synthesise new knowledge that has been critically tested (Imawan & Ismail, 2023; Sun et al., 2023).

4. CONCLUSION

This study confirms that the use of EM3N-based digital worksheets can improve students' critical mathematical thinking skills in various schools. The integration of local cultural elements with a digital learning approach not only improves conceptual understanding but also fosters student motivation and active engagement in the learning process. This is reinforced by qualitative findings, which indicate that teachers and students perceive tangible benefits from the developed media, both in terms of ease of use and relevance to everyday life.

The EM3N-based digital worksheets represent a robust, innovative synthesis. This model combines local cultural relevance (Ethno-Modelling) with a deeply held national pedagogical philosophy (3N – *Niteni*, *Nirokke*, *Nambahi*) to achieve the high-level cognitive objectives required by the deep learning framework. The 3N provide an operational cycle that naturally maps the Ethno-Modelling phase into the constructivist processes of *Niteni* (Critical Contextualization), *Nirokke* (Logical Application), and *Nambahi* (Innovative Reflection). The EM3N-based digital worksheets also collectively increased student learning motivation, an essential prerequisite for engaging in problem-solving that requires critical thinking skills.

Practically, this study contributes to the development of digital learning tools that integrate local wisdom with the 3N pedagogical strategy (*Niteni*, *Nirokke*, *Nambahi*), providing teachers with an innovative media alternative to enhance student motivation and learning outcomes. Theoretically, this study expands understanding of the integration of ethnomathematics, social constructivism, and social learning theory in the context of digital-based mathematics learning. However, this study also has limitations. The sample size included only seven schools, with one class per school, and no control group, so generalizability is considered limited. Technical constraints, such as internet connection and limited devices, also impacted the smooth implementation. Further research is recommended, incorporating an experimental design with a control group, involving more schools in different regions, and testing the long-term sustainability of the use of these EM3N-based digital worksheets.

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Declarations

Author Contribution	: WH: Conceptualization, Investigation, Methodology, Supervision, Writing - original draft, and Writing - review & editing; UA: Data curation, Formal analysis, Investigation, Methodology, Validation, and Writing - review & editing; SAW: Data curation, Formal analysis, Investigation, Methodology, Validation, and Writing - review & editing.
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