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Islamic Education Journal

Stem-C Learning Model for 21st-Century Skills and Islamic Character Development in Muhammadiyah Elementary Schools

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Submitted : 2026-06-20 ; Accepted: 2026-10-14 ; Published: 2026-11-04

ABSTRACT

This study examined a STEM-C (Science, Technology, Engineering, Mathematics, and Character) learning model for developing 21st-century skills and supporting Islamic character development among fifth-grade students in Muhammadiyah elementary schools in West Java. An embedded experimental mixed-methods design was used, with a quasi-experimental quantitative component and qualitative observations and interviews. The quantitative sample comprised 216 students from four schools selected from an eight-school sampling frame. The ANCOVA showed a significant class effect after controlling for pretest scores, $F(1, 213) = 28.711$, $p < .001$, with a partial eta squared of .119. The adjusted model explained 20.3% of the variance (adjusted $R^2 = .203$). Student responses to the 14-item Likert questionnaire averaged 83.27%; the highest aspect was Islamic character (88.50%) and the lowest was communication (78.00%). Qualitative observations and interviews indicated active collaboration, problem-solving, and the application of values such as honesty and responsibility, while also identifying teacher guidance, time constraints, and technical difficulties as implementation challenges. The study contributes an empirically examined STEM-C implementation in Muhammadiyah elementary schools in which Islamic and Muhammadiyah values are integrated into contextual project activities. The findings support the use of STEM-C as a learning model while indicating that claims about long-term character change require further longitudinal and performance-based assessment.

Keywords: *STEM-C learning model, 21st-century skills, 4C, Islamic character, Muhammadiyah elementary schools, mixed methods.*

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INTRODUCTION

Basic education in Indonesia faces persistent challenges in developing the competencies needed for contemporary learning. PISA 2022 reported Indonesian scores of 371 in reading, 379 in mathematics, and 383 in science, all below the OECD average[1]. Within Muhammadiyah education, these challenges are accompanied by the need to maintain an explicit Islamic educational identity[2]. DapodikMu reports 56 Muhammadiyah elementary schools in West Java, indicating a substantial institutional context in which academic competency and Islamic values are developed together.

STEM is commonly used to organize learning around inquiry, problem solving, design, and the application of science and mathematics to contextual problems[3]. Research has associated STEM-oriented learning with the development of 21st-century competencies, including critical thinking, creativity, collaboration, and communication. However, the character dimension is not necessarily integrated into the same instructional process[4]. In the present study, STEM-C refers specifically to a learning model in which science, technology, engineering, and mathematics activities are accompanied by explicit character integration rather than treating character education as a separate instructional component[5].

The conceptual basis of the model combines integrated STEM learning with character education[6]. The STEM component provides the cognitive and procedural structure for contextual problem solving and project work, while the Character component provides an ethical frame for how students conduct and reflect on scientific activities[7]. In the Muhammadiyah context, the observed character dimensions included honesty in reporting project results, responsibility for assigned tasks, discipline, respect for peers, and gratitude to Allah SWT[8]. This framing distinguishes the present implementation from STEM applications in which character is discussed only as a general outcome or hidden curriculum[9].

Previous studies provide evidence that STEM and related STEM-C or STEAM-C interventions can support selected cognitive, social, and character outcomes, but the available literature identified in this study leaves an empirical gap concerning the implementation of a STEM-C learning model that explicitly embeds Islamic and Muhammadiyah values in elementary-school project activities. A second gap concerns the mixed-methods explanation of how students experience the model and what implementation constraints accompany quantitative changes in 21st-century skills[10]. Thus, the novelty claimed here is contextual and instructional rather than a claim that the general idea of integrating STEM and character is entirely new[11].

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This study therefore examines whether implementation of the STEM-C learning model is associated with differences in 21st-century skills between experimental and control groups after controlling for pretest scores, and how observations, interviews, and student responses explain the quantitative findings[12]. The study also examines how Islamic character is manifested during learning activities.[13] By separating measured cognitive outcomes from observed and perceived character indicators, the study aims to provide a more evidence-based account of STEM-C implementation in Muhammadiyah elementary schools.

The research gap is therefore specific: empirical evidence is limited on how Islamic and Muhammadiyah values can be operationalized within STEM-C project activities at the elementary level and interpreted alongside quantitative 4C outcomes[14]. The present study addresses this gap through an embedded mixed-methods design in which qualitative evidence is collected during and after the intervention to explain the quantitative experiment[15].

The objective of this study was to examine the STEM-C learning model as implemented in Muhammadiyah elementary schools in West Java, with particular attention to 21st-century skills, student responses, and observed expressions of Islamic character[16]. The contribution is an empirical description of how the model operates in this religious-school context and of the conditions and limitations that accompany its implementation[17].

METHODS

This study used an embedded experimental mixed-methods design[18]. The quantitative component was the primary strand and used a quasi-experimental comparison of an experimental group receiving the STEM-C learning model and a control group receiving conventional learning[19]. Qualitative data were embedded within the experiment rather than conducted as an independent parallel study: observations were collected during implementation and interviews were conducted after the intervention to explain classroom processes, student experiences, and implementation constraints[20]. In the terminology of Creswell and Plano Clark, the design is an experimental mixed-methods structure in which qualitative information is embedded in a predominantly quantitative study[21]. The study was conducted over an eight-month period (2025–2026) in Muhammadiyah elementary schools in West Java[22].

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The sampling procedure was conducted in two stages to resolve the distinction between convenience and probability sampling. First, an eight-school sampling frame was formed from Muhammadiyah elementary schools that were administratively accessible and ready to participate. The eight schools represented four geographic clusters: Bekasi (Muhammadiyah Elementary School 47 and 09), Tasikmalaya (Muhammadiyah Elementary School Tawang and Singaparna), Bandung (Muhammadiyah Elementary School 4 and 5), and Cirebon (Muhammadiyah Elementary School 1 and 3). Second, four schools were selected from this eight-school frame using cluster random sampling. Thus, convenience sampling describes formation of the eligible sampling frame, whereas cluster random sampling describes the selection of the four participating schools.

The four selected schools were organized into two experimental schools and two control schools. The study therefore does not claim that the four schools represent all Muhammadiyah elementary schools in West Java statistically. The population context consists of 56 Muhammadiyah elementary schools reported by DapodikMu, while the available study data do not provide the total number of students in that population. Consequently, generalization should be limited to the participating school context and interpreted with caution.

All fifth-grade students in the four selected schools participated in the quantitative field trial, producing 216 students (115 experimental and 101 control). Fifth-grade teachers and school principals contributed qualitative information through interviews. The experimental group received STEM-C integrated learning through contextual project activities; the control group continued conventional learning. The supplied research record specifies an eight-month study period but does not provide a reliable session-by-session frequency or a complete intervention schedule. Accordingly, no unsupported number of sessions is added in this revision.

The study used quantitative and qualitative instruments. The quantitative outcome instrument consisted of a 20-item multiple-choice test developed from indicators related to critical thinking, creativity, collaboration, and communication[23]. Because multiple-choice items primarily capture cognitive performance, the present revision does not treat them as direct behavioral measures of collaboration and communication[24]. These social dimensions, together with Islamic character indicators, were examined through observation sheets, interviews, and the 14-item student response questionnaire. The instruments underwent expert judgment and empirical item analysis; 20 items were retained after validity, reliability, discrimination, and difficulty analyses.

The research process follows the Embedded Experimental design presented in the figure[25]: [26]

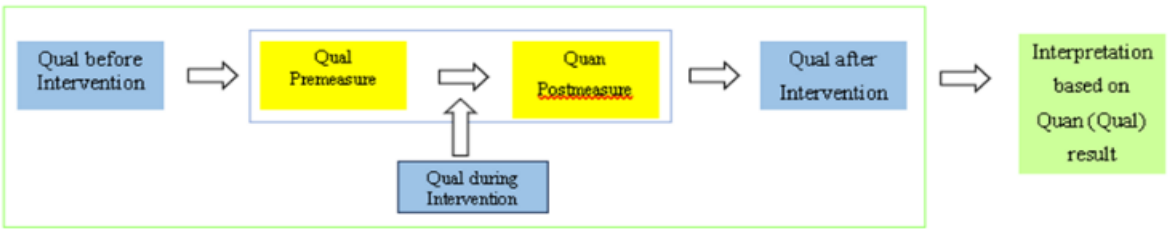


Figure 1. Research Flowchart

The embedded procedure comprised four phases: (1) qualitative observation before the intervention

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[25] Minc and others, 'Mixed Methods Research: A Primer for the Vascular Surgeon'.
[26] Minc and others, 'Mixed Methods Research: A Primer for the Vascular Surgeon'.

for needs analysis; (2) pre-measurement of students' initial abilities; (3) STEM-C intervention accompanied by qualitative observation; and (4) post-measurement followed by qualitative inquiry and integrated interpretation[27]. Thus, qualitative data were positioned before and during the intervention to document context and implementation, and after the intervention to explain student and teacher experiences[28]. The qualitative strand was embedded within the quantitative experiment rather than treated as a separate intervention[29].

Data Collection Procedures

1. Quantitative Data Collection Process

All 216 students completed a pretest before the intervention and a posttest after the intervention. The experimental group participated in STEM-C project activities, while the control group received conventional instruction. The same outcome construct was assessed before and after the intervention to permit ANCOVA using the pretest as a covariate[30].

The quantitative test comprised 20 multiple-choice items aligned with indicators for critical thinking, creativity, collaboration, and communication. The indicators were operationalized as follows: critical thinking involved identifying and analyzing problems and evaluating solutions; creativity involved generating, varying, and elaborating possible solutions; collaboration involved participation, role sharing, responsibility, and response to group differences; and communication involved explaining ideas, responding to others, and presenting project results. Because the test format is primarily cognitive, evidence for collaboration and communication is interpreted together with the observation and questionnaire data rather than as a direct behavioral score[31].

To ensure the quality and accuracy of the measurement tools, the test instruments underwent a theoretical validation process through consultation with experts (expert judgment). After being deemed theoretically sound, the instruments were then empirically tested in the field. The data from these trials are then statistically analyzed to assess the quality of each test item, including validity testing, reliability estimation, discrimination index calculation, and difficulty level analysis. Based on this series of preliminary instrument tests, 20 test items were selected that were deemed valid and met the standards for use in the actual research data collection phase[32].

During the intervention, the experimental group received the STEM-C learning model and the control group received conventional learning[33]. At posttest, students completed the 21st-century skills test and a 14-item student response questionnaire using a 1–4 Likert scale. Questionnaire results were summarized by indicator and overall percentage to describe student perceptions of the learning experience. The questionnaire was not used as evidence of actual long-term character change[34].

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2. The Qualitative Data Collection Process

The qualitative strand was embedded in the quantitative experiment to explain how the STEM-C model was implemented and how students experienced it[35]. Qualitative evidence consisted of non-participant observations during intervention and semi-structured interviews after the intervention[36].

3. Observations (During the Intervention)

The researcher acted as a non-participant observer throughout the STEM-C learning process[37]. The observations focused on the accuracy of the teachers' implementation of the modules and the students' responses to the material[38]. Observation sheets and field notes were used to record the dynamics of student interactions, any technical difficulties that arose, and the students' behavior during the project activities[39].

4. Semi-Structured Interview (Post-Intervention)

In-depth interviews were conducted after the post-test with student and teacher representatives from the experimental group. Interview subjects were selected using purposive sampling based on post-test score variation (high, medium, low)[40]. The interviews aimed to explore in-depth perceptions regarding the STEM-C learning experience. The interviews were recorded using an audio recorder with the participants' consent and were subsequently transcribed and analyzed[41].

Quantitative analysis included normality and homogeneity checks followed by ANCOVA, with posttest 21st-century skills as the dependent variable, class (experimental/control) as the main factor, and pretest score as the covariate. Statistical significance was evaluated at $\alpha = .05$. For the class effect, partial eta squared was calculated from the reported ANCOVA F statistic and degrees of freedom. Model fit was interpreted using R^2 and adjusted R^2. Questionnaire data were summarized by aspect and percentage, with attention to differences among critical thinking, communication, collaboration, creativity, and Islamic character[42]. Qualitative observations and interviews were analyzed descriptively and then integrated with the quantitative findings to explain convergence, variation, and implementation constraints. No causal claim was made from qualitative evidence alone[43].

RESULTS AND DISCUSSION

The findings are reported in three linked components: quantitative changes in the 21st-century skills outcome, student responses to the learning model, and qualitative evidence concerning classroom processes and Islamic character indicators.

Quantitative Data Analysis

Quantitative analysis began with tests of the assumptions for parametric analysis. The Kolmogorov–Smirnov results in Table 1 showed significance values above .05 for the experimental and control pretest

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[43] Minc and others, 'Mixed Methods Research: A Primer for the Vascular Surgeon'.

and posttest scores, supporting the normality assumption. Levene's test in Table 2 also showed p > .05 for the pretest and posttest, indicating homogeneous variances between groups.

The normality of the data in this study was tested using the Kolmogorov-Smirnov test. The decision criteria were based on the probability value (significance). If the probability value is greater than 0.05 (p > 0.05), the data distribution is considered normal. Conversely, if the probability value is less than 0.05 (p < 0.05), the data is considered not normally distributed. The results of this normality assumption test will serve as the basis for determining the subsequent hypothesis testing technique. If the data is proven to be normally distributed, the data analysis will proceed using parametric statistical tests. However, if the data does not meet the assumption of normality, the data analysis will use non-parametric statistical tests as an alternative.

Table 1. Results of the Normality Test for 21st-Century Skills

	Class	Kolmogorov–Smirnov			Conclusion
		Statistic	df	Sig.	
21st-Century Skills	Experimental pretest	,72	115	,200*	Data are normally distributed
	Experimental Posttest	,68	115	,154	Data are normally distributed
	Control Pretest	,81	101	,151	Data are normally distributed
	Control Posttest	,75	101	,121	Data are normally distributed

a. Liliefors Significance Corection

All reported Kolmogorov–Smirnov significance values were greater than .05; therefore, the normality assumption was considered satisfied for the subsequent ANCOVA.

Table 2. Results of the Homogeneity Test for 21st-Century Skills

1		Levene Statistic	Df1	Df2	sig
21st-Century Skills *Pretest*	Based on mean	,732	1	214	, 393
	Based on median	,685	1	214	,409
	Based on median and with adjusted df	,685	1	212,441	,410
	Based on trimmed mean	,710	1	214	,401
21st-Century Skills *Posttest*	Based on mean	1,245	1	214	,266
	Based on median	1,180	1	214	,278
	Based on median and with adjusted df	1,180	1	213,002	,279
	Based on trimmed mean	1,210	1	214	,271

Levene's test was non-significant for both the pretest (p = .393) and posttest (p = .266), supporting the assumption of homogeneous variances.

Table 3. Results of the ANCOVA Test for 21st-Century Skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1,213.457a	2	606.729	28.309	< .001
Intercept	84.520.125	1	84.520.125	3.943.641	< .001
21st-Century Skills Pretest	598.115	1	598.115	27.908	< .001
Class	615.342	1	615.342	28.711	< .001
Error	4,565.016	213	21.432		
Total	90.298.598	216			
Corrected Total	5,778.473	215			

The ANCOVA results in Table 3 showed a significant class effect after controlling for pretest scores, $F(1, 213) = 28.711$, $p < .001$. The corresponding partial eta squared was .119, indicating that the class effect accounted for approximately 11.9% of the variance in the outcome after adjustment for the covariate. The pretest covariate was also significant, $F(1, 213) = 27.908$, $p < .001$, indicating that students' initial scores were related to posttest performance. The overall model was significant, $F(2, 213) = 28.309$, $p < .001$, with $R^2 = .210$ and adjusted $R^2 = .203$; thus, the model accounted for 20.3% of the adjusted variance in the outcome. These results establish a statistically significant group difference after adjustment, but they do not by themselves establish long-term character change or academic achievement effects.

Table 4. Categorization of Survey Response Percentages

Percentage (%)	Category
81–100	Excellent
61–80	Good
41–60	Fair
21–40	Poor
0–20	Very Poor

The 14 questionnaire items were aggregated by assessed aspect and converted to percentages. The categorization criteria are presented in Table 4, while the observed aspect-level results are presented in Table 5.

Table 5. Results of the Analysis of Student Responses

Assessed Aspects	Statement Number	Percentage (%)	Category
Critical Thinking	1,2,3	82,50%	Excellent
Communication	4,5,6	78,00%	Good
Collaboration	7,8,9	85,25%	Excellent
Creativity	10, 11, 12	82,10%	Excellent
Islamic Character	13,14	88,50%	Excellent
Overall Average		83.27	Excellent

The overall student response was 83.27%, classified as Excellent under the criteria in Table 4. This percentage represents students' perceptions of the learning experience rather than an independent measure of learning effectiveness or character change.

The highest response was for Islamic character (88.50%), followed by collaboration (85.25%), critical thinking (82.50%), and creativity (82.10%). Communication was the lowest aspect at 78.00%, although it remained within the Good category. The pattern suggests stronger perceived support for character-related and collaborative dimensions than for communication, which is consistent with the qualitative observation that some students still required teacher guidance when presenting or expressing ideas.

The aspect-level pattern provides a more differentiated interpretation than the overall percentage alone. In particular, communication was 10.50 percentage points below Islamic character (78.00% versus 88.50%). The questionnaire therefore indicates generally positive perceptions but also identifies communication as an area requiring further instructional practice. Because the questionnaire is perceptual, these percentages are not interpreted as evidence of proportional changes in students' actual behavior.

Qualitative Data Analysis

1. Results of the Analysis of STEM-C Learning Observations

Qualitative data from non-participant observation were analyzed descriptively to examine classroom dynamics, implementation fidelity, and manifestations of 4C and character indicators. The observations

were used to explain the quantitative findings rather than to verify statistical effect size.

Observations indicated active participation during project activities. Collaboration was visible through discussion and role distribution, while communication developed unevenly because some students still required teacher guidance during presentations. Critical thinking and creativity were observed when students encountered technical problems and considered alternative solutions. These observations provide contextual support for the quantitative findings but do not establish a direct causal relationship between score changes and behavioral change.

Character-related observations included responsibility for assigned tasks, honesty in reporting project results, respect for peers during differences of opinion, and expressions of gratitude to Allah SWT. These observations were treated as manifestations observed during the intervention rather than as evidence of stable or long-term character development.

The qualitative evidence therefore showed convergence with some quantitative patterns, particularly collaboration and the need to strengthen communication. At the same time, the observations identified implementation constraints, including the need for teacher guidance and technical difficulties during project construction. These variations qualify the interpretation of the overall positive findings.

2. Results of In-Depth Interviews

Semi-structured interviews were conducted with teacher and student representatives from the experimental group. Student participants were selected purposively to reflect high, moderate, and low posttest score categories. The interview evidence was used to explain students' experiences and perceived mechanisms rather than to quantify change in character or 4C performance.

Students described project failure as an opportunity to identify causes and consider alternative solutions. One high-scoring student reported revising project dimensions and materials after an initial failure. This account illustrates how the project context can create opportunities for problem solving and persistence, but a single quotation cannot be generalized to all students.

Interviews also described experiences of collaboration and communication. A student from the intermediate category reported becoming more willing to speak in front of classmates after sharing presentation responsibilities with group members. This account is consistent with the observation that collaboration was relatively prominent, while communication still required continued practice.

Regarding Islamic character, interview data included examples of honesty in reporting failed experiments and gratitude after successful problem solving. These statements illustrate how values were discussed and enacted in particular learning situations. They should not be interpreted as evidence that the intervention produced permanent changes in students' character.

Teachers and students identified time management and technical difficulties during the early stages of project construction as implementation challenges. These findings indicate that the model requires adequate instructional time, teacher facilitation, and technical support.

Overall, the qualitative strand provided explanatory context for the quantitative results while also identifying variation and constraints. The evidence supports the interpretation that STEM-C created opportunities for collaboration, problem solving, communication practice, and value application, but it does not establish that these outcomes changed in direct proportion to the quantitative score difference or persisted after the intervention.

Discussion

The quantitative findings indicate that the experimental and control groups differed significantly in posttest 21st-century skills after adjustment for pretest scores, $F(1, 213) = 28.711$, $p < .001$, partial $\eta^2 = .119$. The significant pretest covariate indicates that initial ability remained relevant to posttest performance. The adjusted R^2 of .203 indicates that the model explained 20.3% of the adjusted variance,

leaving substantial variation unexplained. Therefore, the finding should be interpreted as evidence of a statistically detectable class effect within the study rather than as proof that STEM-C alone accounts for all observed differences.

The qualitative evidence helps explain why the project-based structure may have supported 4C-related learning. Contextual project tasks required students to discuss problems, divide responsibilities, test designs, and revise solutions after technical failures. Such activities are consistent with STEM literature emphasizing inquiry, design, and real-world problem solving as mechanisms for developing higher-order skills. However, the lowest questionnaire score occurred for communication (78.00%), and observations noted that some students still required teacher guidance during presentations. Thus, the model appears to create opportunities for communication practice, but the evidence does not justify treating communication as uniformly improved[44].

The collaboration findings can similarly be interpreted as a process feature of project work rather than as proof of a generalized behavioral transformation. Students reported dividing presentation and project responsibilities, and observations documented group discussion and role distribution. These processes are compatible with research emphasizing teamwork in STEM learning. The questionnaire result for collaboration (85.25%) was higher than communication (78.00%), suggesting that students perceived group participation more positively than oral expression. This difference is important because it shows that the four dimensions of 4C did not develop uniformly in the available evidence.

The Character component provides the contextual contribution of the model. Honesty, responsibility, respect, and gratitude were incorporated into project activities and appeared in observations and interview accounts. The highest questionnaire percentage was for Islamic character (88.50%). Nevertheless, this evidence represents perceptions and observed instances during the intervention; it does not constitute a validated longitudinal measure of character change. The contribution of STEM-C is therefore better described as creating structured opportunities for students to practice and discuss Islamic and Muhammadiyah values while engaging in scientific and engineering activities.

The mixed-methods integration indicates convergence at the level of learning processes: quantitative results showed a significant adjusted class difference, while qualitative data described mechanisms and conditions that may help explain that difference, including project problem solving, role distribution, presentation practice, and teacher facilitation[45]. The qualitative strand also identified time constraints and technical difficulties, preventing an exclusively positive interpretation[46]. The study's contextual novelty lies in examining these processes within Muhammadiyah elementary schools and explicitly connecting project work with Islamic and Muhammadiyah values. The main limitations are the absence of group-level pretest and posttest descriptive statistics in the available statistical output, the use of a multiple-choice test that cannot directly capture all behavioral dimensions of 4C, the limited school sample, and the short-term nature of the character evidence. Future studies should include performance-based 4C assessment, validated character measures, estimated marginal means with confidence intervals, and longitudinal follow-up[47].

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CONCLUSION

The STEM-C learning model was associated with a significant difference in 21st-century skills between the experimental and control groups after controlling for pretest scores, $F(1, 213) = 28.711$, $p < .001$, partial $\eta^2 = .119$. The overall model explained 20.3% of adjusted variance. Student responses were generally positive (83.27%), with Islamic character receiving the highest aspect percentage (88.50%) and communication the lowest (78.00%). Qualitative evidence indicated opportunities for collaboration, problem solving, communication practice, honesty, responsibility, and gratitude, while also identifying teacher guidance, time constraints, and technical difficulties. The findings support STEM-C as a contextually integrated learning model in Muhammadiyah elementary schools, but claims of long-term Islamic character development should be reserved for studies using validated performance-based and longitudinal measures.

ACKNOWLEDGMENTS

The author would like to express his deepest gratitude to the Muhammadiyah Elementary Schools in West Java, particularly to the principals, the faculty, and all the students who provided permission, full support, and active participation throughout the data collection process for this study. Special thanks are also extended to my family and all relevant parties for their guidance, mentorship, motivation, and contributions, which enabled the successful completion of this scientific article.

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