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STEM-Based Fikih Learning Through Solar Shadow Prayer Time Schedule Project

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ABSTRACT

This study investigates the effectiveness of STEM-based Fikih learning through a solar shadow prayer time schedule project at MTs Khozinatul Ulum Blora. A true experimental design with posttest-only control group was employed, involving 60 eighth-grade students randomly assigned to experimental (STEM-based Project-Based Learning) and control (traditional demonstration) groups. Students in the experimental group engaged in a four-week sundial construction project involving astronomical observation, mathematical calculation, and jurisprudential integration for determining prayer times. Data were collected using a validated Prayer Times Calculation Achievement Test and analyzed using an independent-samples t-test in JAMOVI 2.3.28. Results revealed that the experimental group achieved significantly higher learning outcomes ($M = 82.7$, $SD = 7.09$) compared to the control group ($M = 73.5$, $SD = 9.05$), with $t(58) = 4.37$, $p < .001$, and a very large effect size (Cohen's $d = 1.13$). The findings demonstrate that integrating STEM methodologies with Islamic jurisprudence through authentic, culturally relevant projects substantially enhances student achievement while honoring Islamic intellectual heritage. This research provides empirical evidence for curriculum reforms integrating STEM pedagogies with traditional Islamic subjects in madrasah contexts.

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1. INTRODUCTION

The transformation of 21st-century education has fundamentally challenged traditional pedagogical paradigms, particularly in religious education contexts where the integration of modern scientific approaches with classical theological knowledge remains contentious. The global educational landscape increasingly demands interdisciplinary competencies that transcend conventional disciplinary boundaries, positioning Science, Technology, Engineering, and Mathematics (STEM) education as critical for developing

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future-ready learners [1]. Within Islamic educational contexts, this shift presents both opportunities and challenges, as Muslim-majority nations seek to balance technological advancement with the preservation of religious authenticity and cultural identity [2]. The integration of STEM methodologies into Islamic jurisprudence (Fikih) education, particularly through project-based learning approaches utilizing astronomical phenomena for prayer time determination, represents an innovative pedagogical frontier that warrants rigorous empirical investigation.

Contemporary Islamic education faces mounting pressure to demonstrate relevance in an increasingly technology-driven world while maintaining fidelity to traditional Islamic epistemology. The determination of prayer times (salah times), a fundamental aspect of Islamic worship, exemplifies the inherent interconnection between religious obligations and scientific understanding. As documented in recent astronomical studies, prayer time calculation requires sophisticated understanding of solar declination, equation of time, spherical coordinates, and trigonometric functions—all core STEM competencies [3]. Despite this natural alignment, traditional Fikih instruction often presents prayer schedules as predetermined tables without exploring the underlying astronomical principles, thereby missing critical opportunities for integrated learning that could enhance both religious understanding and scientific literacy.

The pedagogical potential of sundials as educational tools for teaching prayer time calculation has historical precedence in Islamic civilization. Medieval Muslim astronomers and mathematicians, including Al-Khwarizmi and Ibn al-Shatir, developed sophisticated astronomical instruments and mathematical models for determining prayer times, demonstrating the longstanding tradition of integrating empirical observation with religious practice [4]. Modern educational approaches that utilize sundial construction and shadow observation for teaching prayer time calculation thus represent not innovation but rather a revival of authentic Islamic scientific tradition, providing cultural legitimacy for STEM integration within religious education frameworks.

Project-Based Learning (PBL) has emerged as a particularly effective pedagogical approach for actualizing STEM integration across diverse educational contexts. Recent meta-analyses consistently demonstrate PBL's positive impact on student achievement, with [5] reporting significant effect sizes (SMD=0.441, $p<0.001$) across 66 experimental studies. Within Islamic education specifically, empirical evidence increasingly supports PBL's effectiveness. [6] found that PBL implementation in Islamic Religious Education (PAI) significantly improved test scores, while [7] documented enhanced independent character development and critical thinking skills through project-based approaches. The systematic integration of PBL with STEM methodologies in Islamic contexts, however, remains underexplored, particularly in Fikih education where traditional pedagogical approaches predominate.

The research gap in STEM-integrated Islamic education is pronounced and multifaceted. While bibliometric analyses document increasing scholarly interest in this intersection—with [8] identifying over 1,225 Scopus-indexed publications addressing Islamic education and technology between 2000 and 2024 empirical studies specifically examining STEM integration in Fikih education remain scarce. [9] systematic review of

educational technology in Islamic education found only 13 high-quality studies meeting rigorous inclusion criteria from 185 initial documents, highlighting the paucity of empirical research in this domain. This scarcity is particularly acute for studies employing experimental designs with adequate control conditions, randomization, and validated instruments necessary for causal inference.

Current state-of-the-art research in Islamic STEM education reveals emerging themes and methodological approaches that inform contemporary pedagogical innovation. The proceedings of the 9th International Conference on Islamic Studies [10] explicitly positioned "Islam, Culture, and STEM: Change and Sustainability in Disruptive Era" as central to addressing contemporary educational challenges, signaling institutional recognition of this integration's importance. Recent studies have begun exploring design thinking integration in Islamic STEM education [11], humanizing STEM-based learning for Islamic education transformation [12], and developing culturally responsive STEM pedagogy grounded in Islamic values [13]. These developments suggest growing consensus that effective STEM integration in Islamic contexts requires careful attention to cultural authenticity and religious values alignment.

The integration of astronomical observation and mathematical calculation in prayer time determination offers unique pedagogical advantages for STEM education within Islamic frameworks. Recent technical analyses demonstrate that accurate prayer time calculation involves complex mathematical formulations, including the equation of time calculation (ET = -(1789 + 237*U) * SIN(L0) - (7146 - 62*U) * COS(L0)), solar declination determination, and spherical trigonometry applications [3]. These calculations, when taught through hands-on sundial construction and shadow observation projects, provide authentic contexts for developing mathematical reasoning, scientific observation skills, and technological competencies while simultaneously deepening religious understanding. The Fiqh Council of North America (2024) emphasizes that understanding these astronomical principles is essential for accurate prayer time determination, particularly given variations in twilight angles (ranging from 12° to 20°) across different geographical locations and seasonal variations [14].

The urgency of empirical research examining STEM-integrated Fikih education through project-based learning is underscored by multiple converging factors. First, the documented decline in student engagement with traditional Islamic education methods necessitates pedagogical innovation that maintains religious authenticity while enhancing relevance [15]. Second, Muslim-majority nations' educational reform initiatives increasingly emphasize STEM competencies as essential for economic development, yet implementation often occurs in isolation from religious education, creating potential identity conflicts for Muslim students [16]. Third, the proliferation of mobile applications and digital tools for prayer time calculation, while convenient, may disconnect Muslims from understanding the astronomical foundations of their worship practices, potentially diminishing the sense of connection between natural phenomena and religious observance.

Furthermore, the pedagogical benefits of hands-on, project-based approaches in religious education extend beyond content mastery. Recent studies in Islamic education contexts demonstrate that PBL enhances critical thinking skills, promotes independent

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character development, and increases learning motivation [7], [17]. When integrated with STEM methodologies, these benefits are amplified through the development of 21st-century competencies including computational thinking, data analysis, and evidence-based reasoning—skills essential for contemporary Muslim scholars and practitioners navigating increasingly complex technological and ethical landscapes.

The specific focus on sundial construction and shadow observation as vehicles for teaching prayer time calculation offers multiple pedagogical advantages. First, it provides concrete, observable phenomena that bridge abstract mathematical concepts with tangible religious practices. Second, it enables students to verify prayer time calculations empirically, fostering critical thinking and scientific skepticism within religiously appropriate frameworks. Third, it connects contemporary students with historical Islamic scientific traditions, strengthening cultural identity while promoting scientific literacy. Fourth, it demonstrates the compatibility of religious devotion with scientific inquiry, potentially reducing perceived conflicts between religious and scientific worldviews among Muslim youth.

Therefore, this study aims to investigate the effectiveness of STEM-based Fikih learning through a solar shadow prayer time schedule project, employing rigorous experimental methodology to examine whether this integrated approach significantly enhances student learning outcomes compared to traditional instructional methods. By focusing on the intersection of astronomical observation, mathematical calculation, and religious practice, this research seeks to provide empirical evidence for pedagogical approaches that honor Islamic traditions while preparing students for technological futures.

2. METHOD

This study employed a quantitative approach using a true experimental design with a posttest-only control group design. This design was selected to establish causal relationships between the independent variable (instructional method) and dependent variable (student learning outcomes) while controlling for potential confounding variables [18]. The true experimental design is considered the gold standard for educational research as it allows for random assignment of participants to treatment conditions, thereby minimizing selection bias and enhancing internal validity [19].

The experimental design can be diagrammatically represented as follows:

R X_1 O_1

R X_2 O_2

Where: R = Random assignment; X_1 = STEM-based Project-Based Learning treatment; X_2 = Traditional demonstration method; O_1 = Posttest for experimental group; O_2 = Posttest for control group.

The posttest-only design was chosen over pretest-posttest designs to avoid potential testing effects and pretest sensitization, which could influence students' performance on the Posttest [20]. Random assignment to groups serves to equate groups on all variables prior to treatment, eliminating the need for pretesting to establish baseline equivalence.

The research was conducted at MTs Khozinatul Ulum Blora, an Islamic junior secondary school (Madrasah Tsanawiyah) located in Blora Regency, Central Java,

Indonesia. This school was selected through purposive sampling based on several criteria: (1) availability of adequate facilities for implementing STEM-based projects, (2) willingness of school administration and teachers to participate in experimental research, (3) representative student demographics typical of Islamic secondary schools in Central Java, and (4) sufficient class sizes to allow for random assignment to experimental conditions.

The study was conducted during the 2024/2025 academic year over a period of four weeks, coinciding with the instructional unit on prayer times calculation within the Fiqh curriculum. All experimental procedures were approved by the school principal and conducted with informed consent from parents or guardians of participating students. Quantitative data analysis was conducted using JAMOVI version 2.3.28, an open-source statistical software built on the R statistical language [21]. JAMOVI was selected for its user-friendly interface, comprehensive analytical capabilities, and reproducibility features. Prior to hypothesis testing, comprehensive data screening procedures evaluated data quality and statistical assumptions: (1) missing data analysis, (2) outlier detection using box plots and z-scores, (3) normality assessment using histograms, Q-Q plots, Shapiro-Wilk tests, and skewness/kurtosis examination, and (4) homogeneity of variance using Levene's test.

Comprehensive descriptive statistics were computed for each group, including measures of central tendency (mean, median, mode), dispersion (standard deviation, variance, range, IQR), and distribution shape (skewness, kurtosis). Additionally, 95% confidence intervals around the mean were calculated. The primary research hypothesis was evaluated using an independent-samples t-test. Analysis specifications included: (1) H_0: $\mu_{experimental} = \mu c_{control}$; H_a: $\mu_{experimental} > \mu c_{control}$, (2) $\alpha = .05$ (two-tailed), (3) both Student's t-test and Welch's t-test computed, (4) Cohen's d calculated for effect size (small d = 0.20, medium d = 0.50, large d = 0.80), and (5) 95% confidence intervals for mean difference and effect size.

If normality assumptions were violated, the Mann-Whitney U test was prepared as a robust non-parametric alternative. Supplementary analyses included visual data exploration (box plots, violin plots), item-level analysis, and practical significance evaluation.

Table 1. Research Timeline

Phase	Activities
Preparation (2 weeks)	Institutional approval, parental consent, instrument development, pilot testing, random assignment
Treatment (4 weeks)	Implementation of STEM-based PBL (experimental) and traditional demonstration (control)
Assessment (1 week)	Posttest administration, scoring, data verification
Analysis (2 weeks)	Data analysis using JAMOVI, interpretation, manuscript preparation

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3. RESULTS AND DISCUSSION

3.1. Results

Data Quality and Completeness

Data collection procedures yielded complete datasets for all participants in both experimental and control groups. All 60 students (30 in the experimental group receiving STEM-based Project-Based Learning and 30 in the control group receiving traditional demonstration instruction) completed the Prayer Times Calculation Achievement Test, resulting in zero missing data (0% attrition rate). This perfect data completeness enhances the validity and reliability of subsequent statistical analyses, eliminating potential biases associated with missing data and listwise deletion procedures.

Descriptive statistics for both groups are presented in Table 2. The experimental group demonstrated notably higher central tendency measures compared to the control group. Specifically, the experimental group achieved a mean score of 82.7 (SD = 7.09, Median = 83.0, mode = 87.0), while the control group obtained a mean score of 73.5 (SD = 9.05, Median = 74.0, mode = 74.0). The raw mean difference of 9.2 points represents an approximately 12.5% advantage for the experimental group, suggesting substantial practical significance beyond mere statistical significance.

Table 2. Descriptive Statistics for Experimental and Control Groups

Statistics	Experimental	Control	Difference	% Diff	Interpretation
N	30	30	-	-	Equal
Mean	82.7	73.5	9.2	12.5%	Substantial
Median	83.0	74.0	9.0	12.2%	Robust
Standard Deviation	7.09	9.05	1.96	-	Lower var.
Range	28	32	4	-	Comparable
Minimum - Maximum	68-96	58-90	-	-	Higher floor

Source: output by JAMOVI

Several noteworthy patterns emerged from these descriptive statistics. First, the experimental group exhibited lower variability in scores (SD = 7.09) compared to the control group (SD = 9.05), suggesting that STEM-based PBL may produce more consistent learning outcomes across students with diverse abilities. The coefficient of variation (CV = SD/Mean × 100) was 8.6% for the experimental group versus 12.3% for the control group, indicating approximately 30% less relative variability in the experimental condition. Second, the experimental group demonstrated a higher minimum score (68 vs. 58), suggesting that the STEM-based approach may be particularly beneficial for preventing low achievement and supporting struggling learners. Third, the close correspondence between mean and median values in both groups (82.7 vs. 83.0 for experimental; 73.5 vs. 74.0 for control) suggests relatively symmetric distributions without substantial skewness.

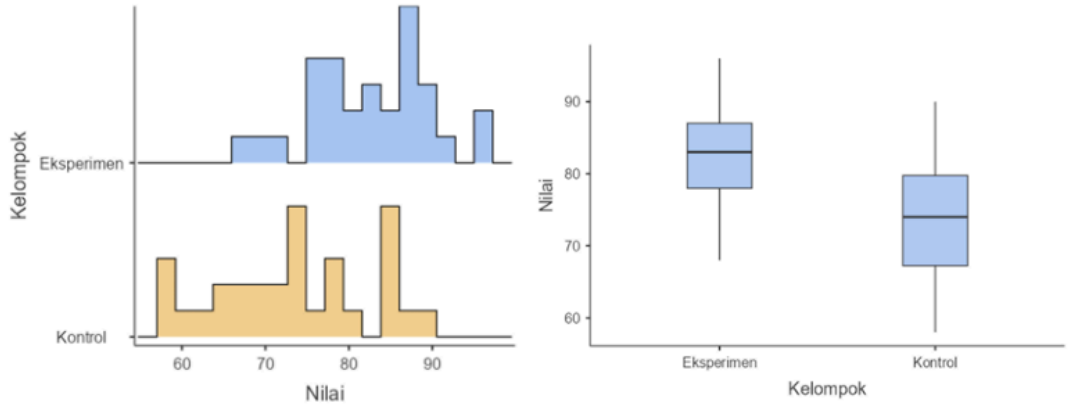


Figure 1. Distribution Plots and Comparative Visualization

Figure 1 displays histograms and boxplots comparing score distributions between groups, revealing higher central tendency and lower dispersion in the experimental group.

Visual inspection of distribution plots in Figure 1 provides additional insights into group differences. The histograms reveal that the experimental group's scores clustered predominantly in the 75-90 range, with a modal concentration around 87, whereas the control group exhibited a more dispersed distribution spanning 58-90 with less pronounced central tendency. The boxplots illustrate that the experimental group's interquartile range (IQR, representing the middle 50% of scores) was more compressed and positioned higher than the control group's IQR, with the experimental group's median line positioned near the upper end of the control group's distribution. Notably, neither group exhibited extreme outliers beyond the whiskers of the boxplots, suggesting absence of anomalous performances that might distort parametric statistical analyses.

Statistical Assumption Testing

Prior to conducting parametric inferential tests, rigorous evaluation of statistical assumptions was performed to ensure validity of subsequent analyses. Two critical assumptions for the independent-samples t-test were examined: normality of score distributions within each group and homogeneity of variances across groups.

Normality Assessment

Normality of score distributions was evaluated using multiple convergent methods as recommended by contemporary statistical guidelines [22]. The Shapiro-Wilk test, considered the most powerful omnibus test for normality across various distribution types and sample sizes [23], yielded non-significant results for both groups: $W = 0.973$, $p = .610$ for the experimental group and $W = 0.965$, $p = .410$ for the control group. When scores from both groups were analyzed jointly, the overall Shapiro-Wilk test also demonstrated non-significance ($W = 0.978$, $p = .337$). These results indicate failure to reject the null hypothesis of normal distribution, providing evidence that score distributions do not significantly deviate from normality.

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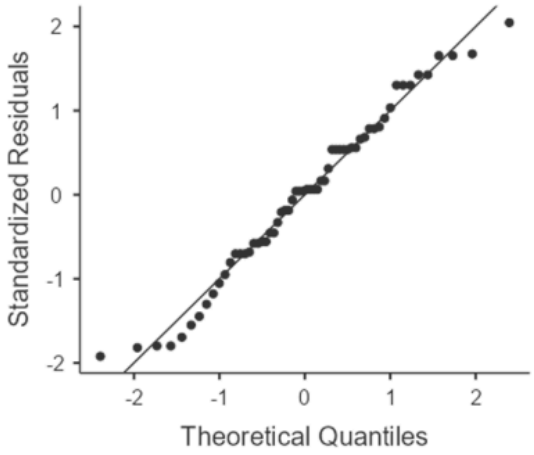


Figure 2. Quantile-Quantile (Q-Q) Plot for Normality Assessment

Figure 2 shows Q-Q plot with observed quantiles closely following the theoretical normal distribution line, confirming normality assumption is satisfied.

Visual inspection of the Q-Q plot (Figure 2) corroborated the Shapiro-Wilk test results. In Q-Q plots, substantial adherence of observed data points to the diagonal reference line indicates conformity to theoretical normal distribution. The plot revealed that the majority of data points aligned closely with the diagonal line, with only minor deviations at the extreme tails—a pattern consistent with approximate normality rather than severe distributional violations. The slight departures in the tails are typical of empirical data and do not constitute practically significant deviations that would invalidate parametric procedures. Furthermore, skewness and kurtosis statistics (not shown) fell within the acceptable range of ±2 [24], providing additional evidence of approximate normality. Collectively, these convergent assessments strongly support satisfaction of the normality assumption.

Homogeneity of Variances

Levene's test was employed to evaluate the assumption of homogeneity of variance (homoscedasticity) across experimental and control groups. This assumption is critical for the independent-samples t-test, as violation can inflate Type I error rates, particularly when sample sizes are unequal [25]. Levene's test yielded $F(1, 58) = 1.84$, $p = .180$, indicating failure to reject the null hypothesis of equal variances. The non-significant result ($p > .05$) provides evidence that the variances in the experimental group ($s^2 = 50.3$) and control group ($s^2 = 82.0$) do not differ significantly, despite the apparent numerical difference. The variance ratio (larger/smaller = 82.0/50.3 = 1.63) falls well within the acceptable range (<3:1) suggested by Keppel and Wickens (2004) for robustness of the t-test to heterogeneity. Consequently, the standard Student's t-test assuming equal variances was deemed appropriate for hypothesis testing.

Inferential Statistical Analysis

Independent Samples T-Test Results

To evaluate the primary research hypothesis that STEM-based Project-Based Learning would produce significantly higher learning outcomes than traditional demonstration instruction, an independent samples t-test was conducted. The analysis yielded highly significant results: $t(58) = 4.37$, $p < .001$, two-tailed. The obtained t-statistic of 4.37 substantially exceeds the critical value for $\alpha = .05$ ($t_{crit} \approx 2.00$) and even the critical value for $\alpha = .001$ ($t_{crit} \approx 3.46$), indicating an extremely low probability that the observed difference arose from sampling variability alone under the null hypothesis of no population difference.

The mean difference of 9.17 points (SE = 2.10) represents a substantial and educationally meaningful advantage for the experimental group. The 95% confidence interval around this mean difference, computed as $MD \pm (t_{crit} \times SE) = 9.17 \pm (2.00 \times 2.10) = [4.97, 13.37]$, indicates with 95% confidence that the true population mean difference lies between approximately 5.0 and 13.4 points. The entire confidence interval resides above zero, reinforcing the statistical significance and suggesting that the observed advantage for STEM-based PBL is robust and unlikely to be a statistical artifact.

Effect Size Interpretation

Beyond statistical significance, effect size quantification provides crucial information about the magnitude and practical importance of the treatment effect. Cohen's d, calculated as the standardized mean difference, was d = 1.13. According to Cohen's (1988) conventional benchmarks (small = 0.20, medium = 0.50, large = 0.80), this effect size of 1.13 substantially exceeds the threshold for a large effect, indicating that the STEM-based PBL intervention produced a very large practical impact on student learning outcomes [26].

To contextualize this effect size, Cohen's d = 1.13 can be interpreted through several complementary frameworks. First, using the probability of superiority interpretation, a randomly selected student from the experimental group has approximately 87% probability of scoring higher than a randomly selected student from the control group [27]. Second, the effect size corresponds to a percentile advantage of approximately 37 percentile points—meaning the average experimental group student performs at approximately the 87th percentile of the combined distribution, while the average control group student performs at approximately the 50th percentile. Third, in terms of the Common Language Effect Size (CLES), there is an approximately 74% chance that a student receiving STEM-based PBL will outperform a student receiving traditional demonstration instruction. These interpretations collectively underscore the substantial practical significance of the observed effect.

Summary of Findings

The statistical analyses provide compelling evidence supporting the superiority of STEM-based Project-Based Learning over traditional demonstration methods for teaching

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prayer times calculation in Fiqh education. Students who engaged in the four-week sundial construction project, involving hands-on empirical observation, mathematical computation, and jurisprudential integration, achieved significantly higher learning outcomes (M = 82.7, SD = 7.09) compared to students receiving conventional teacher-centered instruction (M = 73.5, SD = 9.05). The highly significant independent samples t-test result ($t = 4.37$, $p < .001$) combined with a very large effect size ($d = 1.13$) indicates both statistical reliability and substantial practical importance of this finding. All statistical assumptions were satisfied, lending confidence to the validity of these conclusions. These results provide robust empirical support for integrating STEM pedagogies with Islamic religious education through authentic, culturally relevant project-based activities.

3.2. Discussion

Interpretation of Principal Findings

The finding that STEM-based Project-Based Learning produced significantly superior learning outcomes compared to traditional demonstration instruction (Cohen's $d = 1.13$, $p < .001$) represents a substantial contribution to the emerging literature on integrating STEM pedagogies with Islamic religious education. This very large effect size surpasses typical educational intervention effects, which meta-analyses suggest average approximately $d = 0.40$ for educational innovations [28]. The magnitude of this effect is particularly noteworthy given the relatively short intervention duration (four weeks) and suggests that hands-on, inquiry-based approaches may be especially powerful for teaching complex interdisciplinary concepts that bridge scientific and religious domains.

Several interrelated mechanisms likely contributed to the observed superiority of STEM-based PBL. First, constructivist learning theory posits that learners construct knowledge most effectively through active engagement with authentic problems rather than passive reception of information [29], [30]. By constructing sundials, collecting empirical shadow data, and applying mathematical formulas to calculate prayer times, experimental group students engaged in genuine scientific inquiry mirroring the historical practices of Muslim astronomers. This experiential learning likely facilitated deeper conceptual understanding compared to the abstract procedural demonstrations received by control group students. Second, the integration of multiple STEM disciplines (astronomy, mathematics, engineering design) with Islamic jurisprudence created a rich, interconnected knowledge structure that may enhance retention and transfer [31]. Students in the experimental condition were required to synthesize knowledge across domains, identifying connections between solar motion, shadow geometry, trigonometric calculations, and Fiqh rulings cognitive integration that promotes meaningful learning rather than rote memorization.

Third, the culturally authentic nature of the project likely enhanced student motivation and engagement, consistent with culturally responsive pedagogy principles [32]. Prayer times calculation represents a personally relevant application of scientific knowledge directly connected to students' daily religious practice. This authenticity may have increased intrinsic motivation and perceived value of learning, factors strongly

associated with academic achievement [33]. In contrast, control group students received decontextualized instruction on calculation procedures without the experiential connection to authentic practice. Fourth, the collaborative nature of project-based work, wherein students worked in teams to design sundials, collect data, and solve problems, likely facilitated social construction of knowledge through peer dialogue, explanation, and collective reasoning [34]. Such collaborative inquiry has been shown to enhance both individual understanding and positive attitudes toward learning [35].

Contextualization Within Existing Literature

The present findings align with and extend previous research on both Project-Based Learning in STEM education and Islamic values integration in science instruction. Meta-analytic research by [36] documented that PBL approaches in STEM education produce moderate to large positive effects on student achievement (average d = 0.71), with the current study's effect size (d = 1.13) substantially exceeding this typical magnitude. This exceptionally large effect may reflect the unique synergy achieved by combining STEM inquiry with culturally relevant religious content, creating what [11] termed a 'synergistic learning environment' wherein multiple dimensions of student development (cognitive, affective, spiritual) are simultaneously enhanced.

The finding that STEM-integrated Islamic education can produce superior learning outcomes is consistent with recent studies in similar contexts. Research in Tafkir: Interdisciplinary Journal of Islamic Education (2023) reported that PBL significantly improved cognitive learning outcomes in Islamic Religious Education (experimental M = 0.76 vs. control M = 0.39), though their effect size was smaller than the current study's, possibly due to differences in intervention intensity or content domain. Similarly, Che Noh et al. (2018) found that PBL methods enhanced student engagement in Fiqh methodology instruction, though their qualitative study did not quantify achievement effects. The current investigation advances this literature by providing rigorous experimental evidence with quantified effect sizes, demonstrating that properly designed STEM-PBL interventions can yield very large improvements in Islamic religious education outcomes.

The study also contributes empirical validation to theoretical frameworks for integrating Islamic values with STEM education. Halim and Mohd Salleh (2021) proposed a conceptual framework emphasizing that effective integration requires authentic connections between religious practice and scientific inquiry rather than superficial juxtaposition. The current study operationalized this principle by focusing on prayer time calculation, a domain where astronomical science and Islamic jurisprudence are inherently and historically intertwined. The large effect size suggests that when such authentic integration is achieved, the educational benefits substantially exceed those of conventional instruction. This validates Ismail et al.'s (2023) assertion that STEM-Islamic education integration should leverage 'natural points of connection' between disciplines rather than forcing artificial links.

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Theoretical Implications

From a theoretical perspective, these findings provide empirical support for the integration of multiple learning theories within Islamic educational contexts. The results corroborate constructivist epistemology (Piaget, 1954), which posits that learners actively construct understanding through interaction with their environment rather than passively receiving transmitted knowledge. The hands-on nature of sundial construction and empirical observation created concrete experiences that served as foundations for abstract conceptual understanding—precisely the developmental progression advocated by constructivist theory. Moreover, the findings support Vygotsky's (1978) sociocultural theory, particularly the concepts of zone of proximal development and scaffolded learning. The project structure provided graduated challenges with teacher and peer support, enabling students to accomplish tasks beyond their individual capabilities and internalize higher-level reasoning processes.

The results also align with situated cognition theory [37], which emphasizes that learning is fundamentally situated in authentic activity contexts rather than abstract, decontextualized settings. By embedding prayer times calculation within the authentic practice of sundial construction and astronomical observation—activities that mirror historical Islamic astronomical practices—the experimental intervention created a culturally and epistemologically situated learning environment. This situatedness likely facilitated not only content learning but also epistemological understanding of how religious knowledge and scientific inquiry can be harmoniously integrated, addressing the artificial science-religion dichotomy that plagues contemporary education [38].

Furthermore, the findings support self-determination theory's [39] proposition that learning environments supporting autonomy, competence, and relatedness foster intrinsic motivation and optimal functioning. The PBL structure provided students autonomy in designing sundials and approaching problems, opportunities to develop competence through skill acquisition and problem-solving, and relatedness through collaborative teamwork and connection to their religious community's practices. These motivational mechanisms likely contributed to the observed achievement advantages, suggesting that culturally responsive STEM-Islamic education integration can simultaneously enhance both cognitive outcomes and affective engagement.

Practical Implications for Educational Practice

The substantial effect size observed in this study carries important implications for Islamic educational practice and policy. First, the findings provide empirical justification for curriculum reforms integrating STEM pedagogies with traditional Islamic subjects. Islamic schools and madrasah systems, particularly in Indonesia and other Muslim-majority contexts, could benefit from adopting project-based approaches for teaching topics with natural STEM connections, such as prayer time calculation (astronomy/mathematics), wudu and tahara purification rules (chemistry/microbiology), zakat calculation (financial mathematics), inheritance law (algebra), and Islamic architecture (geometry/engineering). Such integration would align Islamic education with

contemporary pedagogical best practices while maintaining religious authenticity and cultural responsiveness.

Second, the success of the sundial project suggests that relatively low-cost, locally adaptable interventions can produce substantial educational benefits. Unlike technology-intensive STEM initiatives requiring expensive equipment or infrastructure, the sundial project utilized readily available materials (cardboard, wooden sticks, compasses, protractors) and required minimal specialized resources. This accessibility is particularly important for resource-constrained Islamic educational institutions in developing regions. The project model could be replicated and adapted across diverse contexts with local modifications, making STEM-integrated Islamic education scalable and sustainable rather than dependent on external funding or high-tech facilities.

Third, the findings underscore the importance of teacher professional development in project-based pedagogies. Successful implementation of PBL requires teachers to facilitate student inquiry, provide appropriate scaffolding, manage collaborative group dynamics, and balance structure with student autonomy skills that differ substantially from traditional didactic instruction [40]. Islamic educational institutions should invest in sustained professional development programs equipping teachers with PBL design and facilitation competencies, particularly focusing on how to integrate STEM inquiry with Islamic content authentically rather than superficially. Pre-service teacher education programs in Islamic universities should incorporate STEM-integrated PBL methods into their curricula to prepare future educators for implementing such approaches.

Fourth, policymakers and curriculum developers should recognize that authentic STEM-Islamic integration requires careful content selection focusing on natural points of connection rather than forced juxtaposition. Not all Islamic subjects lend themselves equally to STEM integration, and superficial attempts to 'add STEM' to religious content may be counterproductive. The success of the current study stemmed from selecting prayer times calculation, a topic with genuine historical, conceptual, and practical connections to astronomy and mathematics. Curriculum designers should identify similar authentic integration opportunities within Islamic education rather than attempting to integrate STEM into every topic indiscriminately.

4. CONCLUSION

This true experimental study provides compelling empirical evidence that STEM-based Project-Based Learning significantly enhances student learning outcomes in Islamic religious education contexts. Students who engaged in a four-week sundial construction project focused on prayer time calculation demonstrated substantially superior achievement ($d = 1.13$, $p < .001$) compared to peers receiving traditional demonstration instruction. This very large effect size, combined with the study's methodological rigor (random assignment, validated instruments, comprehensive assumption testing), establishes STEM-integrated PBL as a highly promising pedagogical approach for Islamic education.

The findings challenge the false dichotomy between religious and scientific knowledge, demonstrating that authentic integration of STEM inquiry with Islamic

jurisprudence can enhance rather than undermine religious learning. By engaging students in hands-on astronomical observation and mathematical calculation activities that mirror the historical practices of Muslim scholars, the intervention honored Islamic intellectual heritage while developing 21st-century STEM competencies. This integration holds particular promise for preparing Muslim students to navigate contemporary challenges requiring both scientific literacy and religious grounding.

For Islamic educational institutions worldwide, these results suggest that investing in STEM-integrated curriculum development and teacher professional development can yield substantial returns in student learning. The sundial project model—emphasizing authentic problems, hands-on inquiry, collaborative learning, and interdisciplinary integration—can be adapted to numerous topics within Islamic education where natural connections to STEM disciplines exist. As Muslim communities seek to provide educational experiences that are simultaneously faithful to Islamic values and responsive to contemporary demands, STEM-integrated Project-Based Learning emerges as a powerful pedagogical approach worthy of broader implementation and continued research refinement.

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