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Strengthening science teachers' knowledge and practical skills through DNA extraction, PCR, and electrophoresis training

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ABSTRACT

Recent advances in molecular biology require science teachers to have a solid understanding of DNA, genetics, and biotechnology. However, limited laboratory facilities and a lack of hands-on experience remain major challenges in implementing experimental learning in schools. This community service program aimed to strengthen knowledge of DNA concepts and provide practical laboratory experience for junior and senior high school Biology/science teachers from Muhammadiyah schools in the Solo Raya region through training on DNA extraction, PCR preparation, and DNA visualization. The program was conducted using a participatory approach that included planning, hands-on laboratory training, and evaluation through pre-tests, post-tests, and participant satisfaction surveys. Participants practiced selected steps of PCR preparation. Among 15 paired participants, average scores increased from 61.33 to 76.67, and 11 participants improved. Most of the 16 respondents also reported positive perceptions regarding the relevance of the training materials, the quality of the activities, and the usefulness of the program for supporting science learning in their schools. The training enabled participants to connect abstract molecular biology concepts with direct laboratory experience. Practical skills were not assessed with a performance rubric; the findings therefore indicate improved knowledge and initial hands-on experience, not demonstrated skill mastery.

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1. INTRODUCTION

The advancement of molecular biology has driven significant changes in biology instruction at the secondary school level, particularly regarding DNA, genetics, and biotechnology. DNA is no longer understood merely as a theoretical concept; rather, it has become a vital foundation for comprehending how traits are inherited across generations, how genetic information functions within cells, and how this knowledge is utilized in various modern biotechnology developments. Consequently, the mastery of DNA concepts by biology and science teachers at both junior and senior high school levels is essential to ensuring high-quality and meaningful science instruction. Nevertheless, various studies indicate that genetics remains a challenging topic to comprehend due to its abstract and complex nature.

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Research demonstrates that biology undergraduates in Indonesia continue to experience difficulties in achieving a deep understanding of genetics concepts, particularly regarding allele relationships, gene interactions, and their applications in real-world contexts (Rusmana et al., 2021). This condition indicates that strengthening conceptual understanding in genetics must be addressed at the teacher level as the primary facilitator of learning. Furthermore, other studies also confirm that low conceptual comprehension in molecular biology can directly impact the quality of instruction received by students (Haberbosch et al., 2025).

Laboratory activities play a strategic role in bridging abstract concepts with empirical experience. Practical-based learning enables the integration of cognitive aspects and science process skills, thereby allowing both students and teachers to construct a deeper understanding. Systematic review results indicate that well-designed laboratory activities can assist in enhancing conceptual understanding, scientific skills, and student engagement in science instruction (Oliveira & Bonito, 2023). In the context of molecular biology, DNA extraction and visualization practical work serves as an effective approach to concretize DNA concepts that have traditionally been abstract. Furthermore, research in biology education also demonstrates that the combination of direct laboratory experience and pedagogical reflection can enhance teachers' self-efficacy regarding their instructional capabilities (Haberbosch et al., 2025). The implementation of molecular biology laboratory activities in secondary schools continues to encounter various challenges. Limitations in laboratory facilities, the availability of equipment and practical materials, as well as teacher readiness in managing experimental activities remain hurdles to the execution of practical-based learning (Susilo & Amirullah, 2018). Many schools still rely on theoretical approaches when teaching genetics subject matter due to these constraints. On the other hand, although virtual laboratories can serve as an alternative under certain conditions, direct practical experience retains advantages in building stronger scientific skills and conceptual understanding (Oliveira & Bonito, 2023; Shambare, 2024). Consequently, there is a need for simple practical-based learning innovations that can be implemented utilizing readily obtainable materials and applicable procedures within school environments.

Efforts to strengthen teacher competence through molecular biology training have been reported in several community service initiatives. DNA isolation training for biology teachers in Gowa Regency was reported to enhance teacher comprehension of DNA concepts as well as their proficiency in isolating DNA using simple materials and tools (Ali et al., 2023). A workshop for senior high school biology teachers across Jakarta combined conceptual presentations, DNA isolation practice, and the introduction of biotechnology laboratory equipment, which participants evaluated as beneficial through questionnaires (Seprianto et al., 2022). Molecular genetics training for senior high school biology teachers in Bojonegoro Regency encompassed micropipetting practice and DNA isolation alongside the introduction of polymerase chain reaction and electrophoresis principles, resulting in post-test scores shifting toward higher ranges (Sugiharto et al., 2026). At the junior high school level, simple DNA isolation technique training for science teachers has also been conducted, although its evaluation remains qualitative (Kusumaningrum et al., 2026). Building upon these initiatives, training programs that integrate DNA extraction, polymerase chain reaction preparation, and electrophoresis while evaluating changes in teacher knowledge across both junior and senior high school levels warrant further development and comprehensive evaluation.

These challenges were similarly identified among Muhammadiyah secondary school biology and science teachers in the Soloraya region. Based on interviews and online questionnaires during the needs analysis stage involving 6 science and biology teachers, the participants stated that DNA extraction and visualization practical work constitutes an essential requirement in genetics instruction. Approximately 60 percent of the respondent schools possessed simple laboratory facilities but had never conducted DNA

practical work. These laboratories generally consisted of basic facilities lacking polymerase chain reaction and electrophoresis devices. The primary hurdles impeding laboratory utilization for DNA practical work included limited equipment and materials, a lack of technical experience in executing molecular biology practical activities, and instructional time constraints. Furthermore, all teachers reported never having participated in similar training while exhibiting extremely high enthusiasm for joining DNA extraction training programs. This condition indicates a disparity between instructional needs and implementation readiness in the field. Studies on teacher professional development indicate that practice-based training and mentoring can significantly enhance teacher pedagogical and professional competence (Desimone & Garet, 2015; Morina et al., 2025).

The participants of this program originated from two educational levels, specifically junior high school science teachers and senior high school biology teachers, because both groups operate under the same Muhammadiyah Primary and Secondary Education Council of Soloraya and similarly require the reinforcement of DNA concepts as a foundation for genetics and biotechnology instruction. Furthermore, cross-level training enables limited polymerase chain reaction and electrophoresis devices to be utilized more efficiently within a single activity. The benefits for both groups vary. For junior high school teachers, DNA extraction is not entirely related to specific subject matter, yet it enriches scientific perspectives and science literacy while assisting teachers in explaining modern biological developments contextually. For senior high school teachers, this activity aligns more closely with genetics and biotechnology subject matter, enabling it to be adapted into classroom practical work.

Building upon these conditions, this community service program was designed to reinforce DNA comprehension among junior and senior high school science and biology teachers affiliated with Muhammadiyah Soloraya through DNA extraction and visualization practical activities. This program focuses not only on enhancing conceptual understanding but also on introducing and practicing simple molecular biology laboratory steps adaptable within school settings. In addition, this activity is expected to foster experiment-based instructional innovation. More broadly, the program also supports efforts to enhance educational quality as reflected in Sustainable Development Goal 4 regarding quality education (United Nations Department of Economic and Social Affairs, 2023). This community service program aims to improve DNA conceptual comprehension while providing direct practical experience in DNA extraction, polymerase chain reaction preparation, and DNA visualization via electrophoresis for junior and senior high school science and biology teachers.

2. METHODS

This community service activity was implemented using a participatory approach oriented toward enhancing teacher capacity through a series of stages involving the implementation team and partners collaboratively. The activity design was structured systematically, ranging from needs identification and training execution to program evaluation. This approach aligns with the principles of teacher professional development, which emphasize contextual relevance, active participant engagement, and sustained impacts on instructional practices (Desimone & Garet, 2015; Morina et al., 2025). Furthermore, utilizing practical work as the core of the activity was grounded in findings that experiment-based learning can significantly enhance conceptual understanding and scientific skills (Oliveira & Bonito, 2023).

Planning Stage

The planning stage commenced with partner identification and confirmation through coordination with the Muhammadiyah Primary and Secondary Education Council of Soloraya and Muhammadiyah

secondary school principals. Participants were capped at a maximum of 20 biology and science teachers. Subsequently, a needs analysis was conducted via online questionnaires to identify the level of DNA conceptual understanding, practical experience, and the condition of school laboratory facilities. These data served as the baseline for program evaluation. Based on the analysis results, the team compiled a simple DNA extraction and visualization training module tailored to school conditions, concerning both material availability and implementation feasibility.

Training Stage

The training stage was executed through hands-on practice, specifically focusing on DNA isolation and visualization. This activity was designed to ensure that participants acquired contextual learning experiences through the application of simple procedures adoptable within school environments. The training commenced with simple DNA extraction practical work utilizing readily obtainable materials, namely bananas, dragon fruit, bean sprouts, and melons. During this activity, participants practiced the stages of sample disruption, cell lysis using detergent, salt addition to assist in the separation of cellular components, and DNA precipitation utilizing alcohol. Conceptually, the DNA extraction process involves cell membrane disruption, the separation of DNA from proteins, and DNA precipitation using organic solvents, which can be performed via simple procedures utilizing household materials (Green & Sambrook, 2019; Tan & Yiap, 2009). Recent studies indicate that simple material-based DNA extraction practical work enhances conceptual comprehension and participant engagement in molecular biology instruction, primarily by providing direct experiences that bridge abstract concepts with empirical observations (Hearn & Arblaster, 2010; Levesque et al., 2023; Supriyanti et al., 2021).

Subsequently, participants engaged in DNA visualization training utilizing gel electrophoresis. This activity focused on introducing the principles of biomolecule separation based on size and electrical charge, enabling participants to comprehend that extracted DNA can be further observed through basic molecular biology laboratory techniques (Lee et al., 2012). Participants also practiced pipetting samples into gel wells and observing DNA migration utilizing miniPCR Gelato devices. Through the combination of simple DNA extraction and electrophoresis, participants acquired empirical experiences that assisted in connecting abstract concepts with real-world practice. This practice-oriented training approach is relevant for supporting more meaningful science instruction and has been shown to reinforce conceptual understanding as well as teachers' self-efficacy regarding their instructional capabilities (Haberbosch et al., 2025).

Following DNA extraction, participants were introduced to the principles and stages of Polymerase Chain Reaction (PCR) utilizing ITS primers. The PCR reaction mixture was prepared beforehand by the implementation team, whereas participants added the extracted DNA template into the reaction tubes. Consequently, participants were introduced to and practiced selected steps of PCR preparation rather than the entire process of PCR assembly, optimization, and operation.

Evaluation Stage

Program evaluation was conducted quantitatively and descriptively through two primary instruments, specifically a knowledge test (pre-test and post-test) and a participant satisfaction questionnaire. The knowledge test utilized a pre-test and post-test design to measure improvements in DNA conceptual understanding and practical procedure knowledge; this test was not intended to evaluate practical skill performance. The test instrument comprised 10 multiple-choice items with a maximum score of 100, structured based on indicators of conceptual understanding and simple

procedural knowledge as detailed in the matrix grid (Table 1). Instrument administration was conducted online via Google Forms (GForm) filled out by participants following the activity. Out of 19 participants, 3 participants did not take the pre-test and post-test due to technical constraints, yielding evaluation data from 16 training participants. Because data for these three participants were unavailable, differences in their characteristics, such as teaching level and practical experience, could not be analyzed, which is noted as a limitation. Among these 16 participants, 15 participants provided complete paired pre-test and post-test data, enabling the score change analysis to be performed on 15 paired datasets, whereas the satisfaction questionnaire was analyzed from 16 respondents. The questionnaire covered aspects including satisfaction with training materials and methods, achievement of learning objectives, clarity of material delivery, and remaining challenges encountered. Utilizing GForm was selected due to its efficiency, accessibility, and capability for rapid, systematic data collection and analysis in training-based community service activities (Sumarni, 2024). Participants' practical skills, such as DNA extraction, pipetting, and electrophoregram reading, were observed descriptively during the activity and visually documented, yet were not evaluated using a structured performance matrix; thus, outcome claims in this article are restricted to knowledge enhancement and initial practical experience.

Table 1. Knowledge test blueprint (pre-test and post-test)

Aspect	Indicator	Total Items
Basic DNA concepts	Explaining the structure and function of DNA as genetic material, as well as its replication	1
Principles of DNA extraction	Explaining the stages of DNA extraction (sample disruption, cell lysis, separation of cellular components, precipitation) and the function of the materials used	3
Principles of PCR	Explaining the objectives, reaction components, and stages of PCR	3
Principles of gel electrophoresis	Explaining the principle of DNA separation based on size and electrical charge	3

3. RESULTS AND DISCUSSION

Results

Activity implementation

The community service activity was conducted on February 7, 2026, from 08:30 to 14:00 Western Indonesian Time (WIB), and was attended by 19 participants comprising junior and senior high school biology and science teachers from Muhammadiyah schools across the Soloraya region. The activity commenced with an opening session, followed by the delivery of technical material regarding the implementation of the training to ensure that participants understood the activity flow, working principles, and basic procedures to be performed throughout the training (Figures 1A and 1B). This orientation stage is vital because some participants lacked direct experience in molecular biology practical work. In the context of teacher professional development, an initial phase that provides clarity regarding objectives, procedures, and activity structure proves essential in supporting participant engagement and the effectiveness of professional learning (Ventista & Brown, 2023).

The subsequent training was implemented through a hands-on practice approach (Figures 1C and 1D). Each group performed DNA extraction from different biological materials, namely bananas, dragon fruits, bean sprouts, and melons. The selection of diverse materials was intended to demonstrate that DNA can be isolated from various biological sources that are simple, easily accessible, and close to the context of school instruction. A direct practical approach becomes more meaningful when participants not only manipulate materials directly but also comprehend the concepts underlying each step

performed. Consequently, participants do not merely execute procedures, but also construct scientific understanding from these activities (Oliveira & Bonito, 2023).

The execution of DNA extraction utilizing materials familiar in daily life demonstrates strong pedagogical value. As explained in the Introduction, for junior high school science teachers, this activity may not be entirely related to specific subject matter in class, yet it remains important as a form of scientific insight enrichment and science literacy reinforcement. Meanwhile, for senior high school teachers, this experience is more relevant as it bears a closer connection to genetics and biotechnology subject matter. Laboratory experiences, whether virtual or direct, have been reported to enhance conceptual understanding and teachers' self-efficacy in teaching science (Haberbosch et al., 2025).



Figure 1. (a) Opening; (b) Presentation of training material; (c) and (d) Hands-on practice by participants

Following the DNA extraction process, the activity proceeded with DNA amplification utilizing the Polymerase Chain Reaction (PCR). Because the samples utilized originated from eukaryotic plant tissues, amplification was conducted using ITS (Internal Transcribed Spacer) primers. In its execution, the PCR reaction mixture had been prepared beforehand by the committee, whereas participants added the extracted DNA template from their respective groups. This strategy was selected during the brief training so that participants still acquired direct experience in one of the PCR preparation steps within a realistic timeframe. Consequently, participants were introduced to and practiced selected steps of PCR preparation; this activity was not intended to train the entirety of PCR stages, such as reaction mixture formulation, optimization, and PCR machine operation, meaning comprehensive mastery of PCR cannot be claimed. While the PCR process took place, participants also received reinforced material regarding DNA, DNA replication, PCR operating principles, and its applications in biology and biotechnology. A training model combining practical experience, conceptual reinforcement, and structured facilitation such as this is consistent with the characteristics of effective professional development (Ventista & Brown, 2023).

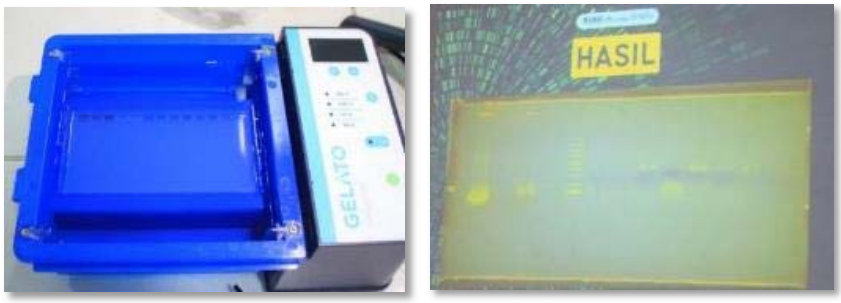


Figure 2. (a) Electrophoresis apparatus; (b) Electrophoregram

The subsequent stage was the visualization of extracted DNA and PCR results utilizing gel electrophoresis. Participants were provided the opportunity to pipette DNA samples into gel wells, which for many participants constituted a first-time experience. This situation created a tense yet enthusiastic atmosphere, indicating both emotional and cognitive engagement among participants throughout the learning process. The electrophoresis process was conducted utilizing miniPCR Gelato devices, enabling DNA migration to be observed directly (Figures 2A and 2B). The visual and direct nature of this stage is vital because it assists participants in connecting abstract concepts regarding DNA and PCR with observable empirical evidence. Literature concerning practical science instruction indicates that direct laboratory experiences contribute to conceptual understanding, procedural skills, and learning motivation, particularly when participants can observe tangible connections between theory and experimental outcomes (Oliveira & Bonito, 2023).

The electrophoregram in Figure 2B illustrates the DNA ladder separating into distinct bands, the extracted DNA bands appearing more prominent in the initial lanes, and the PCR amplification bands appearing fainter with varying intensity across lanes. This pattern indicates that DNA extraction via simple procedures yields DNA capable of visualization, whereas the weak amplification band intensity in several lanes signifies that amplification was not yet optimal; this can be attributed to the non-uniform purity and concentration of DNA templates derived from fresh materials. For participants, this outcome is meaningful in two respects: DNA, which was initially abstract, can be visualized as bands, and imperfect results serve as subjects of discussion regarding factors influencing extraction and PCR success, such as sample quality, DNA purity, and reaction conditions.

Overall, the implementation of the training demonstrated that this activity serves not only as a medium for material transfer, but also as a vehicle for establishing laboratory experience for teachers. This is crucial because effective science instruction is insufficient through lectures alone, necessitating space for practical experiences. Recent research also demonstrates that authentic experiences in molecular biology instruction make a positive contribution to the development of teachers' instructional self-efficacy and pedagogical readiness (Haberbosch et al., 2025).

Evaluation of participant learning outcomes based on pre-test and post-test

The evaluation of participant learning outcomes was conducted utilizing a pre-test and post-test to observe changes in comprehension following the training, which was recapitulated from 15 participants with complete paired pre-test and post-test data. Overall, the results indicate an enhancement in learning achievement following the activity. The mean pre-test score was 61.33, whereas the mean post-test score increased to 76.67. Consequently, there was a mean increase of 15.34 points; this increase is reported descriptively as statistical testing was not performed. Furthermore, the lowest score increased from 20

on the pre-test to 50 on the post-test, whereas the highest score reached 100 on the pre-test and 90 on the post-test. Out of 15 participants, 11 individuals (73.3 percent) experienced a score increase, 1 individual (6.7 percent) maintained a constant score, and 3 individuals (20.0 percent) experienced a score decrease (Figure 3).

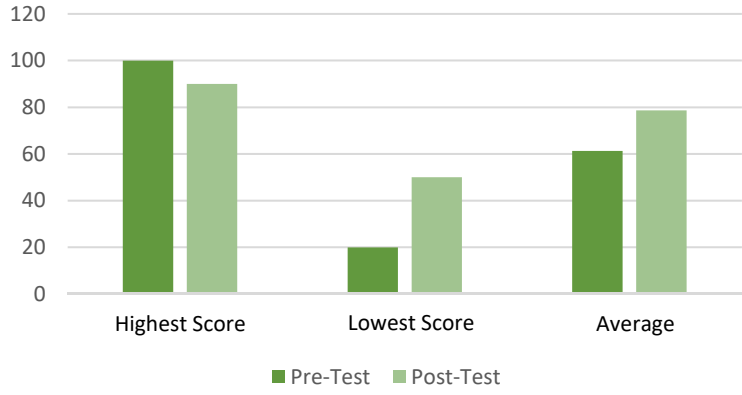


Figure 3. Histogram of pre-test and post-test results

These findings indicate that the training made a positive contribution to participants' comprehension of the trained material, although the design without a control group precludes causal attribution. The increase in the post-test mean indicates that following the series of activities, participants possessed better mastery compared to prior to the training. In the context of training evaluation, utilizing a pre-test and post-test design is commonly employed to capture changes in participant knowledge or competence before and after intervention. Recent studies on secondary school science teacher training also demonstrate that the pre-test and post-test format is effective for identifying enhancements in pedagogical and content knowledge following targeted professional development programs.

The majority of participants demonstrated a substantial score increase. Several participants experienced gains ranging from 20 to 60 points, indicating that the training was not only practically engaging but also associated with enhanced participant comprehension of the presented concepts. These results align with findings that structured teacher professional development, relevant to participant needs, and focused on active learning experiences tends to yield a stronger impact on teacher knowledge and practices (Desimone & Garet, 2015; Ehlert & Souvignier, 2023). According to Ventista & Brown (2023), meaningfully designed teacher professional learning can support improved learning outcomes, whereas the study by Ehlert & Souvignier (2023) emphasizes the importance of material alignment, execution structure, and participant engagement in determining training program effectiveness.

The enhancement in participant learning outcomes can also be understood from the characteristic of the training, which utilized a hands-on practice approach. In this activity, participants not only received theoretical explanations but also engaged directly in DNA extraction, the addition of DNA templates in the PCR process, and DNA visualization via gel electrophoresis. Literature indicates that practical work activities contribute to enhancing conceptual understanding, science process skills, and participant learning engagement, particularly when implementation is clearly connected to the scientific concepts being studied. Therefore, the increase in the post-test scores among the majority of participants in this activity is suspected to be related to the direct learning experience during the training, as practical work assists participants in comprehending material more concretely and meaningfully (Abrahams & Reiss, 2012; Haberbosch et al., 2025).

Nevertheless, several participants experienced a score decrease on the post-test. This finding warrants careful scrutiny. A score decrease does not necessarily indicate that the training was ineffective, but rather may be influenced by several factors, such as participant fatigue following the practical session, time constraints while completing the post-test, varying levels of concentration, or differences in initial participant capabilities. In short-term training, post-test results can indeed be influenced by situational factors beyond content mastery. Therefore, the interpretation of pre-test and post-test data should not rely solely on individual score changes, but rather be integrated with other supporting data, such as observations of activity implementation and participant satisfaction questionnaire results. An evaluation approach combining multiple data sources is considered more appropriate to comprehensively depict training effectiveness.

Participants' practical skill achievement

The practical skills trained in this activity included sample preparation and DNA extraction, pipetting, adding DNA templates to the PCR mixture, loading samples into gel wells, and reading electrophoregrams. Each group conducted DNA extraction from different materials, and participants were given the opportunity to pipette samples into gel wells, which for many represented a first-time experience (Figures 1C, 1D, and 2A). However, this activity did not incorporate structured performance assessments; thus, the proportion of participants capable of independently conducting DNA extraction, correctly pipetting, explaining the function of each stage, or interpreting electrophoresis results cannot be reported. Consequently, the term reinforcement in this article is defined as the reinforcement of knowledge and initial practical experience, rather than evidence of skill mastery. Performance evaluation using a structured rubric matrix (Table 3) is recommended for future activities.

Activity evaluation

Activity evaluation was conducted through a satisfaction questionnaire completed by 16 respondents out of the 19 total participants (Table 2). The questionnaire results indicated that the activity received highly positive feedback. Regarding the alignment of material with participant needs, 56.3 percent of respondents strongly agreed and 43.8 percent agreed. For the indicator concerning the relevance of the DNA visualization topic to school instruction, 50.0 percent of respondents strongly agreed and 50.0 percent agreed. These results demonstrate that participants perceived the delivered material as relevant, serving both as content reinforcement for senior high school teachers and as scientific insight expansion for junior high school science teachers (Ehlert & Souvignier, 2023; Ventista & Brown, 2023).

Positive responses were also evident regarding the quality of material delivery. A total of 50.0 percent of respondents strongly agreed and 50.0 percent agreed that the speaker's explanations were easily understood and delivered systematically. On the indicator assessing the utility of practical work in facilitating comprehension of DNA and RNA concepts, 68.8 percent of respondents strongly agreed and 31.3 percent agreed. This finding indicates that participants considered the hands-on practice training approach helpful in comprehending relatively abstract concepts. These results align with the review by Oliveira & Bonito (2023), which emphasizes that the primary strength of practical activities lies in their ability to connect practical skills with conceptual understanding.

Regarding infrastructure and facilities, 75.0 percent of respondents strongly agreed and 25.0 percent agreed that the facilities adequately supported the execution of the activity. This positive assessment indicates that facility readiness constitutes a supporting factor in training success. In laboratory-based

activities, adequate equipment and material support heavily dictate the quality of participant learning experiences, as good facilities enable activities to run smoothly and meaningfully (Oliveira & Bonito, 2023). Nevertheless, regarding the alignment of implementation time with the material and activities, participant responses were slightly more varied. Specifically, 56.3 percent of respondents strongly agreed, 31.3 percent agreed, 6.3 percent moderately agreed, and 6.3 percent strongly disagreed. These data suggest that while time allocation was generally considered satisfactory, a small proportion of participants felt the activity duration was not entirely ideal. This finding is understandable given that the training encompassed multiple laboratory stages simultaneously, ranging from DNA extraction and PCR to gel electrophoresis, each requiring dedicated time for explanation, demonstration, practice, and result interpretation. Literature on teacher professional development similarly indicates that duration, sustainability, and opportunities for reflection constitute critical elements influencing professional learning quality (Ehlert & Souvignier, 2023; Liu et al., 2025; Ventista & Brown, 2023).

Table 2. Participant satisfaction questionnaire results (Percentage of respondents, n = 16)

Indicator	SS	S	CS	TS	STS
The material aligns with my needs as a Biology/Science teacher	56.3	43.8	0	0	0
The topic of DNA visualization (extraction, PCR, and electrophoresis) is relevant to the Senior High School Biology/Junior High School Science curriculum	50.0	50.0	0	0	0
The speaker's explanations were easily understood and delivered systematically	50.0	50.0	0	0	0
Practical work activities helped me comprehend DNA and RNA concepts better	68.8	31.3	0	0	0
Infrastructure and facilities (laboratory, equipment, and materials) supported the smooth execution of the activity	75.0	25.0	0	0	0
The execution time was appropriate for the material and activities provided	56.3	31.3	6.3	0	6.3
The activity provided valuable new experiences for school instruction	75.0	25.0	0	0	0
I am motivated to integrate the activity outcomes into classroom instruction	50.0	43.8	6.3	0	0
Overall, I am satisfied with the implementation of the activity	62.5	37.5	0	0	0

Note: SS = "*Sangat Setuju*" ("Strongly Agree"); S = "*Setuju*" ("Agree"); CS = "*Cukup Setuju*" ("Moderately Agree"); TS = "*Tidak Setuju*" ("Disagree"); STS = "*Sangat Tidak Setuju*" ("Strongly Disagree'). Percentages in each row may total 99.9–100.1 percent due to rounding.

Regarding the indicator assessing the utility of the activity in providing new experiences for school instruction, 75.0 percent of respondents strongly agreed and 25.0 percent agreed. Meanwhile, for the indicator measuring motivation to integrate activity outcomes into classroom instruction, 50.0 percent of respondents strongly agreed, 43.8 percent agreed, and 6.3 percent moderately agreed. These results indicate participants' intentions to utilize the activity outcomes in their teaching; however, such intentions do not constitute evidence of actual classroom implementation. For junior high school science teachers, the impact may manifest as content enrichment that enhances self-efficacy in contextually explaining modern biological developments. For senior high school teachers, the impact may involve reinforcing genetics, DNA, and biotechnology topics through a more applied approach. These findings align with synthesis evidence indicating that relevant and structured teacher professional development can support changes in instructional practices and improved learning outcomes (Liu et al., 2025; Ventista & Brown, 2023).

Overall, participant satisfaction with the entire activity was also remarkably high, with 62.5 percent of respondents strongly agreeing and 37.5 percent agreeing. This outcome indicates that the training

on DNA extraction, PCR, and gel electrophoresis was perceived as delivering a positive and meaningful learning experience for participants. Considering the participant profile comprising both junior and senior high school science teachers, the activity was evaluated positively by participants, both in terms of material relevance and its ability to bridge molecular biology concepts with easily understandable hands-on learning experiences. However, participant satisfaction must be distinguished from competence enhancement and implementation impact in schools; satisfaction serves as a supporting indicator rather than primary evidence of community service success. Therefore, laboratory training-based service models such as this are worthy of continuation and refinement, particularly regarding time management so that each practical stage and discussion can proceed more optimally (Ehlert & Souvignier, 2023; Oliveira & Bonito, 2023; Ventista & Brown, 2023).

Discussion

At baseline, all surveyed teachers (n = 6) had not previously attended similar training, and approximately 60 percent of the respondents' schools had never conducted DNA practical work despite possessing basic laboratories. Grounded in these baseline conditions, the training provided hands-on experience involving DNA extraction from simple materials, the addition of DNA templates to pre-prepared PCR reaction mixtures, and sample loading into gel electrophoresis, accompanied by conceptual reinforcement regarding DNA, replication, and PCR principles.

Following the training, the mean knowledge score increased by 15.34 points (from 61.33 to 76.67) among 15 participants, with 11 participants (73.3 percent) experiencing score gains. This enhancement is descriptive, given that no statistical testing was performed and no control group was present; thus, it cannot be fully attributed to direct practical work alone. The most defensible interpretation is that hands-on experiences assisted participants in concretizing initially abstract concepts, aligning with findings that practical activities explicitly connected to scientific concepts support conceptual understanding (Abrahams & Reiss, 2012; Oliveira & Bonito, 2023). Conversely, score decreases observed in three participants and a wide range of pre-test scores (20–100) indicate variations in initial participant readiness.

This pattern resembles other community service activities targeting biology teachers. DNA isolation training in Gowa Regency reported improvements in conceptual understanding and teachers' ability to isolate DNA using simple materials (Ali et al., 2023), while molecular genetics training in Bojonegoro Regency reported a shift in post-test scores toward higher ranges following micropipetting and DNA isolation practice (Sugiharto et al., 2026). Compared with activities whose evaluations were limited to satisfaction questionnaires or qualitative assessments (Kusumaningrum et al., 2026; Seprianto et al., 2022), this activity incorporates pre-test and post-test data, though structured skill performance assessments remain absent.

The satisfaction questionnaire results must be interpreted proportionally. Participant satisfaction, competence enhancement, and school implementation impact constitute distinct dimensions. High satisfaction (62.5 percent strongly agreeing and 37.5 percent agreeing) alongside participant motivation to integrate activity outcomes into classroom instruction serve as supporting indicators rather than primary evidence of success. In this article, evidence of competence enhancement is restricted to knowledge scores, whereas classroom implementation impact was not observed. Regarding implications for school practice, this activity provides teachers with the experience and foundation to adapt simple DNA extraction practical work utilizing readily accessible materials (such as bananas, dragon fruits, bean sprouts, and melons), whereas PCR and gel electrophoresis generally still require higher education facilitation due to the lack of equipment in schools.

4. CONCLUSION AND RECOMMENDATIONS

The training activity on DNA extraction, PCR, and DNA visualization via gel electrophoresis enhanced the conceptual knowledge of DNA among junior and senior high school Muhammadiyah Science/Biology teachers across Solo Raya, while providing initial practical experience in selected molecular biology procedures. Among 15 participants with complete data, the mean score increased from 61.33 on the pre-test to 76.67 on the post-test. Furthermore, the majority of participants provided positive feedback regarding the material, training methods, and activity utility for school instruction. This training provided hands-on experiences that assisted teachers in connecting abstract molecular biology concepts with laboratory practice, thereby establishing a foundation for reinforcing teachers' professional competence in practical-based science instruction. Practical skill enhancements, however, cannot be concluded as performance rubrics were not utilized.

This activity presents several limitations. First, practical skills were not evaluated using performance matrices; hence, skill enhancement cannot be inferred. Second, PCR training was limited because the reaction mixture was prepared by the organizing team, with participants only adding the DNA templates. Third, the pre-test and post-test design lacked a control group and statistical testing, involved a small sample size ($n = 15$), and the characteristics of three non-tested participants could not be compared. Fourth, classroom implementation impact was not observed because evaluation was conducted immediately following the activity.

Future activities should incorporate performance assessments utilizing rubric matrices (Table 3) administered before and after training, complemented by structured observations and appropriate statistical testing when sample sizes are sufficient. Similar initiatives should be conducted sustainably with a broader coverage of molecular biology topics, such as bioinformatics-based DNA analysis, species identification using DNA barcoding, or other modern biotechnology applications. In addition, continued mentoring is required for teachers to adapt simple DNA extraction practicals for school instruction in accordance with facility availability. Collaboration among universities, schools, and professional teacher organizations must also be strengthened continuously to support teacher competence development and innovative science instruction implementation.

Table 3. Proposed performance assessment rubric matrix for follow-up activities

Assessed Performance	Observed Indicator
DNA extraction	Performs sample disruption, cell lysis, and DNA precipitation in the correct sequence independently
Pipetting	Draws and transfers sample volumes according to procedure without cross-contamination
Sample preparation	Prepares materials, samples, equipment, and labeling according to procedure
Understanding PCR procedure	States the components of the reaction mixture and PCR cycle stages along with their functions
Conducting electrophoresis	Loads samples into gel wells and operates the device correctly
Reading electrophoregrams	Identifies size markers and DNA bands, and interprets the presence or absence of bands
Explaining procedures to students	Explains the function of each stage using language appropriate for student grade levels

Note: Each indicator is scored on a 1–4 scale (1 = unable to perform; 2 = able to perform with assistance; 3 = able to perform independently; 4 = able to perform independently and explain to others). Results are reported as the percentage of participants in each category.

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