STEM Education with Interdisciplinary Active Teaching and Learning Practices

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***Abstract*—This study reports an account of practices for Science, Technology, Engineering, and Mathematics (STEM) educators implementing interdisciplinary approaches with active teaching and learning curriculum design. A small-scale program evaluation of a two-week Fulbright Specialist professional development workshop was conducted at Universitas Negeri Jakarta (UNJ), Indonesia to support STEM lecturers' competencies in active teaching and learning. The workshop focused on STEM education, backward design, project-based learning, and integrated assessment strategies. Mixed research methodology was applied by quantifying the qualitative input. Data was collected from written reflections, observer notes, structured response forms and participants' learning design products. Findings indicated that participants gained new understanding in STEM learning design, concept mapping, and active learning implementation. Moreover, the findings suggest that structured professional development workshops can support STEM educators' pedagogical competencies while also highlighting the need for continued support in assessment design, interdisciplinary collaboration, and reflective teaching practices.**

***Keywords*—active teaching and learning, backward design, project-based learning, STEM education, interdisciplinary programs**

I. Introduction

The hypothesis of this study is active learning applied to real world problems with Project-Based Learning (PBL) modules elevates and enhances efficiency of learning. It is also a hope the result will be greater engagement and possible real-world solutions. As recently as May 23, 2026 (reported in Jakarta's Antara News) [1, 2], the Indonesian Higher Education, Science, and Technology Minister, Brian Yuliarto, urged universities to strengthen STEM education when "he stressed the importance of strengthening synergy among universities, industries, government and communities".

This approach to solution generation includes necessary Science and Mathematics while also focusing on the Technology and Engineering needed to implement the remedies. By working interdepartmentally, resources are used more effectively. Empirical evidence supporting the use of active learning over traditional, passive lecturing in Science, Technology, Engineering, and Mathematics (STEM) is substantial [3]. Decades of discipline-based education research have demonstrated that engaging students through problem-solving, peer discussion and structured inquiry directly improves academic performance and retention. In a landmark meta-analysis comparing student performances with active learning versus traditional teaching researchers analyzed 225 studies across multiple STEM disciplines [4]. The results revealed student improvements in examination scores by roughly 6% and average failure rates for traditional lecturing dropped from nearly one-third to 21.8% under active learning [4]. The positive effects held true across all STEM disciplines and all class sizes with the most pronounced advantages occurring in smaller classes ($n \leq 50$) [4]. These facts convinced the educational leadership in Indonesia to push the use of active learning techniques and the education of instructors at all levels to enable them to teach with active learning modules.

Additionally, a comprehensive follow-up meta-analysis by Xu [5] screened 1659 papers published between 2010 and 2017. His analysis evaluated 134 high-quality studies with identical or formally equivalent exams, and his research confirmed the persistent value of student engagement. Active learning students scored significantly higher than their strictly lectured peers and improved exam scores by 0.519 standard deviations [5]. Furthermore, the positive impact was highly correlated with the intensity of engagement. Courses utilizing "high-intensity" active learning—where students were actively on-task for at least two-thirds of the class period—yielded much stronger performance gains than lower-intensity implementations [5].

A study utilizing Bayesian regression analyses across a massive multi-institutional dataset found that active learning narrowed achievement gaps in examination scores by 33% and reduced gaps in overall course passing rates by 45%. This data suggests that structured, active environments level the playing field by offering explicit support, immediate feedback, and collaborative structures to the underrepresented student groups that benefit from most disproportionality [6].

Faculty Mathematics and Natural Science is a college in Universitas Negeri Jakarta (One of Government Pedagogical Universities in Indonesia) that educates future STEM educators and pre-service teachers which is also supported by Zhang's [7] view in pre-service teachers' perspectives. For in-service to benefit teachers, there are training programs for professional development organized by universities and international organizations [8]. For instance, teachers and future teachers can attend international exchange programs

such as Erasmus+ or the Fulbright Programs [9, 10].

However, many lecturers who provide training to educate future STEM teachers lack the capacity to design an integrated STEM lesson within their monodisciplinary approach. Moreover, the 2025 policy in Emancipated Learning Curriculum by the Indonesia Government requires an integrated approach to STEM education in each level from early childhood to higher education. Lecturers from Biology, Computer Science, Chemistry, Mathematics, Physics, and Statistics are required to develop integrated STEM design-based learning with contextual problems. Innovative processes and approaches within educational technologies can improve STEM education by offering new ideas to attract more students, close the gender gap, and encourage hands-on learning [10, 11]. Some scholars comment that STEM should be taught as a cross-disciplinary learning design to better engage students in applying integrated knowledge to complete a project or solve a complex problem [10, 12].

The collaboration of co-teaching offers an inclusive practice increasingly used to provide the best support for students with diverse learning needs and encourages collegial working relationships among the University's faculty [13, 14]. It is obligatory in the new Indonesian Educational Policy that lessons apply project- and case-based learning. Some lecturers found it challenging to understand how to use a STEM educational framework with design-based, project-based and case-based learning and include the utilization of an integrated approach for assessment.

Placing students at the center of educational procedures and processes assists their understanding of why and when to apply various instructional technologies. It is a step towards a global and holistic mindset in which all subjects work together to develop students' innovation of critical thinking and problem-solving skills [10]. One of the major challenges of implementing integrated STEM instruction is the shift required from segregated disciplinary instruction to creating meaningful connections between STEM disciplines [15, 16]. Patel stated that one of the biggest educational challenges for K-12 STEM education is that few models exist for teachers to follow regarding how to teach using STEM integration approaches in their classroom [17, 18]. Scholars emphasized that some key features of integrated STEM education are the breaking down of disciplinary boundaries, the meaningful integration of content, and the contextualizing of learning in authentic scenarios [16]. This change represents a paradigm shift from traditional, lecture-based instruction to a student-centered learning method that emphasizes inquiry, problem solving, and real-world relevance [16, 19].

Interdisciplinary approaches are still limited in the Indonesian curriculum and teacher education programs. Existing professional development programs often focus more on general teaching strategies than on practical integrated STEM learning design, assessment alignment, or active learning implementation. Therefore, this study examined how a Fulbright Specialist's professional development workshop supported STEM lecturers in understanding and learning design development for active learning in interdisciplinary STEM education. It included reflections on active teaching from the workshop participants.

This project brought in fulbright specialist, Dr. Li-Jen Lester. She is a full professor in the Computer Science Department and Associate Dean of the College of Science and Engineering Technology at Sam Houston State University, SHSU, Huntsville Texas, USA [20]. She was selected and brought resources for the STEM lecturers to support their curriculum with active teaching and learning strategies. The workshop, held August 12–23, 2024, successfully collaborated on a project titled "Developing Teacher Educator Competencies in STEM Design-Based Learning" [20]. This collaboration was expertly managed by a dedicated team which consisted of the Dean of the Faculty of Mathematics and Natural Sciences at Universitas Negeri Jakarta (UNJ) and the Head of the STEM Education Centre [20]. The program took place at the Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta (FMIPA UNJ) [21]. The workshop aimed to enhance the professional teaching competencies of teacher educators in implementing STEM, design-based learning.

By the end of training many memorable friendships evolved, and appreciation developed between the varied academic disciplines. There have been further collaborations in 2025 to support the UNJ students and faculty including a faculty training workshop and Middle School STEM Seminars. Together, comprehensive workshops have been delivered to benefit the Indonesian community.

Throughout the August 2024 workshop, FMIPA UNJ lecturers engaged in structured learning about the STEM education framework. They focused particular emphasis on design-based approaches. Core components included the creation of learning objectives with coupled activities and the development of assessment strategies within a STEM context. The sessions facilitated the utilization of a variety of instructional methods including lectures, group work, concept mapping, backward design, discussions, and hands-on activities.

Witnessing the remarkable engagement from the group of 24 involved lecturers, this workshop displayed tremendous active participation. 70% of the 24 lecturers were newly hired and some were set to begin their first semester of teaching STEM in September 2024. Others brought experience from teaching at the secondary education level. Through this training, the lecturers collaborated with subject matter experts to design integrated projects and support each other's teaching practices [20].

At the end of this project, three main objectives met expectations:

- STEM lecturers' understanding of STEM Education Framework improved.
- STEM lecturers' competencies in developing STEM design-based learning were enhanced.
- STEM lecturers' competencies in developing STEM project-based and case-based learning improved [22].

However, there were some areas identified as gaps needing to be addressed in future practices:

- An efficient timeline needed for formulating learning outcomes needs to be developed.
- Introduce more types of assessments to fit into various subject areas.
- Create a timeline for implementing teaching and learning within the curriculum designs.

This project aimed to provide global resources to support STEM education by implementing innovative teaching and learning strategies within an interdisciplinary approach. The research hypothesis was that two weeks of implementation from the Fulbright Specialist Workshop was needed to build a strong competency of STEM educators being able to create innovative strategies in their teaching and learning practices. This study specifically investigated how the STEM lecturers experienced the Fulbright Specialist professional development workshop. It included their perceived learning gains, instructional design development, and challenges related to active learning and interdisciplinary STEM lesson planning.

II. Literature Review

The workshop was organized into the following sections to allow each to address a different dimension of STEM design-based learning. These sections are outlined as follows:

A. STEM Education

Saad *et al*. [19] provided the foundation for more sustainable STEM education by helping educators and curriculum designers align existing pedagogical methods with the interdisciplinary and innovation-driven nature of STEM. The integration of STEM education and sustainable development was shown to promote learners' environmental awareness, systems thinking, and critical reflection on global issues. These competencies are crucial for navigating today's complex and interconnected world [16, 19, 23–27]. Habibaturrohmah *et al*. [28–31] stated that embedding educational sustainable development in STEM curricula promotes interdisciplinary knowledge and sustainable mindsets which empower students to act as responsible global citizens.

Contemporary perspectives have extended constructivist thoughts toward socio-constructivism and experiential directions [32, 33]. Toma *et al*. [34] proposed a socio-constructivist didactic model that frames learning in collaborative, interdisciplinary and inquiry-based environments, particularly relevant for integrated STEM education. STEM education can help students make connections between what they learn and what they do [10]. To innovate, there needs to be time and space for creativity and opportunities to develop critical thinking [10]. Professional development is needed to help teachers use new methods efficiently in their STEM classrooms [10].

B. Bloom's Taxonomy

The Taxonomy of Educational Objectives was published in 1956 [35] and revised in 2001 [36]. The revision focused on the original Taxonomy from transitioning to a two-dimensional structure including the knowledge and cognitive process dimensions [37]. The revised taxonomy modernizes the hierarchy by shifting from nouns to verbs and introducing metacognitive knowledge to emphasize the active nature of learning and self-reflection [37]. Anderson *et al*. [36] restructured the framework in the following manner:

The Knowledge Dimension describes the type of content being learned, ranging from concrete to abstract.

- Factual Knowledge: basic elements, terminology, and discrete facts essential to discipline.
- Conceptual Knowledge: Understanding the interrelationships among basic elements within a larger structure, such as theories, models, and principles.
- Procedural Knowledge: Knowledge of how to do something, including methods of inquiry, techniques, algorithms, and specific subject skills.
- Metacognitive Knowledge: Awareness and knowledge of one's own cognitive processes and strategic knowledge for problem-solving.

The Cognitive Process Dimension describes the mental actions used to engage with knowledge ordered from lower order to higher-order thinking skills [37].

- Remembering: Retrieving, recognizing, and recalling relevant knowledge from long-term memory.
- Understanding: Determining the meaning of instructional messages through activities like interpreting, exemplifying, and summarizing.
- Applying: Carrying out or using a procedure in a given situation.
- Analyzing: Breaking material into constituent parts and detecting how they relate to one another.
- Evaluating: Making judgments based on criteria and standards through checking or critiquing.
- Creating: Putting elements together to form a novel, coherent whole or original product.

For this project, a Learning Assessment Deck of Cards was designed and used to plan effective assessments and apply them to learning outcomes for the STEM context. The cards were also used to design new learning objectives and "augment existing sets of learning objectives with constructively aligned assessment strategies [38]".

C. Backward Design

STEM course designs typically contain a healthy mix of learning activities based on course outcomes and assessments (formative and summative) that measure the degree to which those outcomes are met [39]. Fink introduced Integrated Course Design, which incorporates the core principles of backward design by focusing on initiating the design process through identifying desired learning goals before planning assessments and instruction [40]. McTighe and Wiggins [41] developed the three stages of the backward design process for curriculum planning.

Stage 1: Identify Desired Results—define big ideas and lasting understandings at the conclusion of the learning.

Stage 2: Determine Assessment Evidence—create assessment tasks before the lessons to show achievement of the learning objectives identified in stage one.

Stage 3: Plan Learning Experiences and Instruction—engage in learning activities to achieve goals that can be used to best enable students to gain the skills and knowledge needed for success.

D. Active Teaching and Learning

According to Fosnot and Perry [42], the active learning perspective defines learning as an interpretive, recursive, and self-organizing process where learners actively construct meaning by interacting with the physical and social world. This approach emphasizes constructing knowledge through cognitive conflict, reflection, and social mediation, rather

than passive reception. However, a few issues were mentioned by Martella and Schneider [43] within the current active learning literature.

- There is confusion surrounding what "active" in active learning refers to.
- The extensive variation in active learning activities occurs in both research and practice.
- The dichotomy that has been created between active learning and lecture.

Active learning is a classroom situation in which the instructor and instructional activities explicitly afford students agency for their learning, empower teachers and inspire students [10, 44]. According to Pijl-Zieber [19, 45], knowledge is constructed based on prior understanding shaped by the learner's experiences and interaction with their environment. Martella and Schneider [43] stated whether the "active" aspect of active learning should be focused on cognitive activity, behavioral activity, or both remains an open question that, if answered, would provide insight into why active learning is effective.

There are many tools and solutions available for schools. The overwhelming offerings along with educators' lack of time and strict curriculum demands make it difficult for schools to choose the most appropriate trends [10]. Martella *et al*. [46] found that the average number of active learning and other pedagogical features included in active learning college courses was five. These five activities selected by individuals include, but are not limited to, activity sheets, clicker questions, case studies, class projects, group tasks, purposeful tutoring, student presentations, tutorials and games, whole class discussion, lectures, student quizzes, learning/exam preparation, and homework. From a practical standpoint, systematically studying the combination of different types of activities could help instructors refine how they select specific activities to use in their courses and help them determine how and whether to combine different types of activities to promote student learning [43].

E. Project-based Learning

It is important to help students relate the content and what is happening in their environment. Solutions for today's problems require critical thinking, creativity, problem-solving, and innovation [1, 10]. The key principles emerging from effective PBL in STEM education are characterized by the development of flexible knowledge and skills, active metacognitive reasoning, intrinsically motivated collaboration, and engagement with problems situated in rich real-world contexts [15].

Lee *et al*. [47] studied and discovered STEM PBL students have greater mathematics engagement compared to the non-STEM PBL students. The results of his study indicated that highly situated and integrated instruction has a positive impact on students' perceptions of their effective mathematical engagement. Calabrese, and R.M. Capraro also confirmed that the results demonstrated that the implementation of STEM PBL positively influences students' creativity [48]. STEM PBL is an instructional approach characterized by its student-centered, interdisciplinary, collaborative and occasionally technology-driven nature [49].

From many research results, the PBL STEM learning model can be an effective learning strategy to implement integrated STEM education and improve students' scientific creativity [50–52]. Smith *et al*. echo that "the study outcomes provided evidence of informed support for teachers who may be considering the value of adopting a PBL approach in school-based STEM education [15]".

III. Materials and Methods

This section describes the Fulbright Specialist workshop as a professional development program and explains the research procedures used to evaluate participants' experiences. It begins with research design, followed by the workshop procedures, data collection, data analysis, and ethical considerations.

A. Research Design

This study employed a small-scale program evaluation designed to examine a two-week Fulbright Specialist professional development workshop for university STEM lecturers [20]. The evaluation focused on participants' experiences, perceived learning gains, challenges, and learning design products developed during the workshop. The data included participants' written reflections, observer notes, structured response data, and lesson plans and learning design products produced by each participant.

Through this design, the study documented how participants experienced the professional development process and how they began to apply the workshop materials in their own STEM lesson plans. The study examined both participants' perceptions of the workshop and the initial instructional products developed during the program.

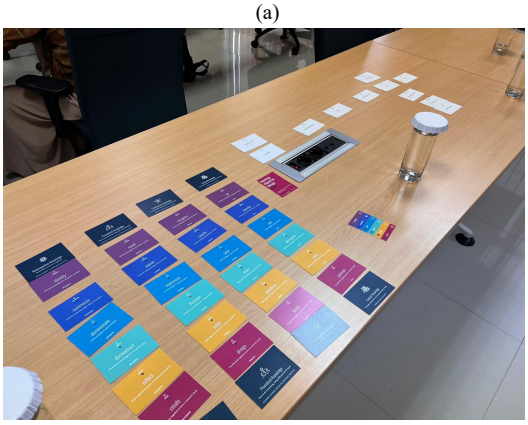
B. Workshop Procedure

The workshop activities were organized to support collaboration, knowledge exchange and capacity building among the Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta (FMIPA UNJ) lecturers. The workshop commenced with an introduction to the STEM Education Framework and STEM Curriculum. The following day, the focus shifted to STEM design-based learning, supported by project-based learning, case-based learning, and integrated assessment strategies in STEM education. These sessions were intended to provide participants with a conceptual foundation for designing active and integrated STEM learning experiences.

Participants were also introduced to the newly enhanced Bloom's Taxonomy through flashcard activities. The flashcards were intended to strengthen their understanding of the cognitive domains in learning design. Participants were asked to arrange a deck of flashcards according to the four knowledge dimensions in the revised Bloom's Taxonomy: factual, conceptual, procedural, and metacognitive knowledge [36]. Fig. 1(a) shows participants discussing and arranging the flashcards, while Fig. 1(b) shows the intended ordered learning assessment design deck. This activity was used to enhance participants' understanding of different types of knowledge and how they relate to students' cognitive learning processes. By using Bloom's Taxonomy as an organizing framework, participants were guided to design learning outcomes, instructional activities, and assessment strategies to align with the knowledge dimensions represented on the cards.



(a)



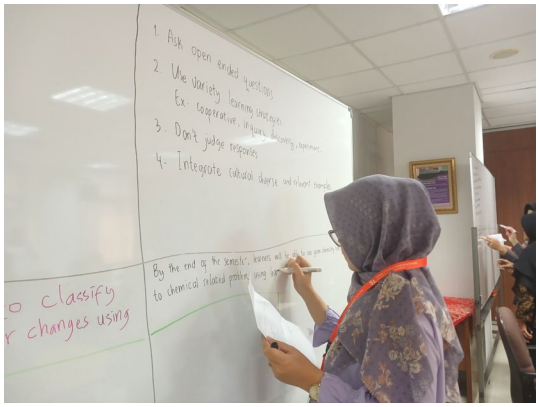
(b)

Fig. 1. Bloom's taxonomy flashcards. (a). Participants discussing and arranging Bloom's Taxonomy flashcards. (b). Arranged learning assessment design deck used to connect knowledge dimensions with learning design.

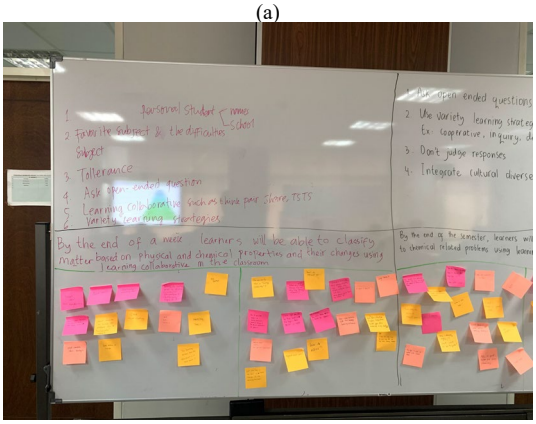
Building on their conceptual understanding, participants engaged in the creation of STEM, Design-Based Learning (DBL) lessons. Working collaboratively in groups and each participant developed a learning design tailored to the courses they currently teach. The project began with cross-disciplinary group discussions involving lecturers from different fields including chemistry, physics, mathematics, and biology. Within these discussions, participants constructed lessons by considering students' prior knowledge and the specific characteristics of the subject matter. Fig. 2(a) shows a participant constructing an initial lesson learning design on the whiteboard, while Fig. 2(b) shows an initial learning design displayed on the whiteboard for suggestions and feedback from other participants.

To support collaborative idea development, each group created a concept map on the whiteboard outlining its proposed learning design. Groups then exchanged and reviewed one another's concept maps, providing constructive feedback to refine the coherence, relevance, and practicality of the designs. This iterative process allowed participants to critically reflect on their approaches while drawing insights from different disciplinary perspectives. Fig. 3(a) shows participants and the facilitator discussing a group concept map during the learning design activity.

The subsequent activity required participants to construct individual mind maps as representations of their learning designs. Each mind map incorporated key elements including the subject topic, time allocation, learning outcomes, instructional methods and assessment strategies. Participants then presented their concept maps to the group and received constructive feedback from both their peers and the seminar facilitator. Based on this feedback, they revised their initial design to improve coherence and applicability. Fig. 3(b) shows a participant presenting an individual concept map to peers and the facilitator.



(a)



(b)

Fig. 2. STEM lesson learning design. (a). Participant constructing an initial STEM lesson learning design on the whiteboard. (b). Initial STEM learning design displayed with subsequent peer suggestions and feedback on sticky notes.



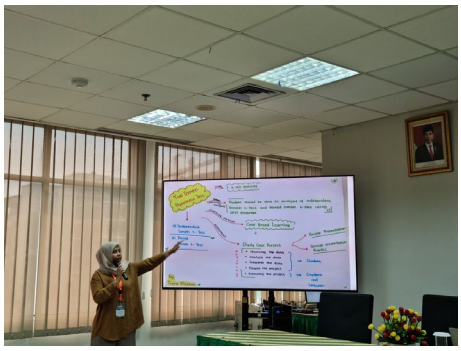
(a)



(b)

Fig. 3. Concept map presentation. (a). Participants and facilitators discuss a group concept map for STEM learning design. (b). Participant presenting an individual concept map for peer and facilitator feedback.

In the final stage of the STEM PBL seminar lesson each participant presented their completed learning design to the entire seminar of learners. These presentations provided an opportunity for participants to explain how they integrated STEM into their instructional plans [53]. The presentations allowed peers and the facilitator to discuss the applicability of the designs to classroom contexts and to provide feedback for further improvement. Fig. 4(a) and (b) show participants presenting their completed STEM learning designs.



(a)



(b)

Fig. 4. Presentation for STEM learning design. (a). Participant presenting a completed STEM learning design. (b). Participant presenting another completed STEM concept map.

The facilitator also provided direct feedback during the presentation sessions. The feedback addressed conceptual, pedagogical and technical dimensions of the proposed learning designs. The lesson designs included the clarity of cross-disciplinary integration alignment with intended learning outcomes and the feasibility of implementation strategies in classroom contexts. This feedback was intended to support participants in refining their designs, improving the coherence of their learning models and preparing the designs for possible classroom implementation. Fig. 5 shows the facilitator providing feedback to participants during the presentation session.

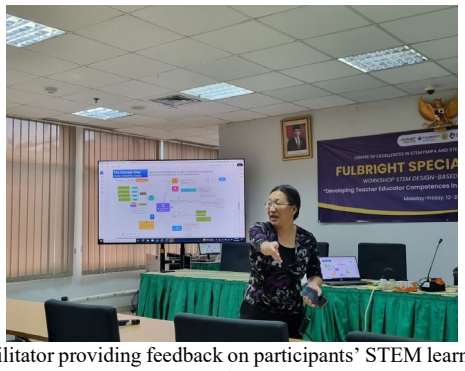


Fig. 5. Facilitator providing feedback on participants' STEM learning design products.

C. Data Collection

Data was collected from four sources: participants' written reflections, observer notes, structured response data, and their learning design products. These sources were selected to document participants' experiences during the workshop along with their perceived learning gains and challenges and the instructional products they created as part of the professional development program. This approach is consistent with educational program evaluation practices wherein data sources and data collection instruments are selected based on the evaluation purpose and questions. The Program Evaluation Toolkit also explains that program assessment may involve identifying data sources, developing data collection instruments, conducting basic analyses and sharing findings with stakeholders [54].

Written reflections were collected during and at the conclusion of the workshop. These reflections documented participants' learning experiences, perceived benefits, challenges, and suggestions for improvement. The reflections prompted participants to describe what they learned, the difficulties they experienced and how the workshop supported their understanding of active teaching and learning in STEM education.

Observer notes were collected by the workshop observers during the activities. These notes documented participants' engagement, group interactions, difficulties during the learning design activities, and responses to peer and facilitator feedback. Structured response data was also collected on the workshop reflection and evaluation forms. These responses included participants' selections of categorized answers related to workshop benefits, difficulties, interaction, instructor roles, microteaching and faculty support.

In addition, participants submitted STEM lesson learning design products developed during the workshop. These products included lesson plans, concept maps, and presentation materials. The products were used to document how participants organized learning outcomes, instructional activities, STEM integration and assessment strategies in their own teaching subject areas.

Reflection and evaluation forms were designed to assess the program and were aligned with the workshop objectives, activities, and expected learning design products. Because the purpose of the study was to evaluate participants' experiences within a specific professional development program, the forms were program-specific rather than standardized measurement scales.

D. Data Analysis

Data was analyzed using descriptive quantitative summaries and qualitative reviews. Structured response data from the reflection and evaluation forms were summarized using frequencies and percentages. For single-response items, percentages were calculated based on the number of participants who answered the item. For items that allowed more than one response, percentages were calculated based on the total number of responses recorded for that item. These descriptive summaries were used to present participants' reported benefits, difficulties, interaction patterns, instructor roles, microteaching experiences and faculty support during the workshop. For questionnaires used in mixed method

research, validity and reliability standards are critical [55]. The subsections below state the control processes for this research project.

1) Reliability

An important step in the beginning of the process was to determine the group of people to be involved in the study. The decision was made to use an in-service composed of new STEM teachers. This group participated in the collaborative efforts as new hires with a focus on integrated active learning. The hope was to encourage them to study and gain access to and establish rapport between the departments involved. The goal here was to assist in carrying forward the habit of interdepartmental active learning methods. It was thought participants would provide data from an array of possibilities and present a rationale for the selected data collection process [56]. Questionnaires often solicit respondents' opinions about topics and issues. The questions were designed to collect the respondents' true opinions [55]. Therefore, the content of the questionnaire items represented constructs to determine whether the respondents expressed similar opinions on measures of the same type [55].

This mixed research method applied written reflections and observer notes reviewed descriptively to support the interpretation of the structured response data. The researchers read the written responses and the observation notes to identify repeated points related to participants' learning experiences. Highlighted areas were perceived gains, challenges and suggestions for improvement. These points were organized according to the main response categories collected from the evaluation forms. The categories included workshop benefits, difficulties in formulating learning outcomes, challenges in designing assessment, peer interaction, instructor roles, and facilitator feedback. Representative quotations were selected to illustrate the main points reported by participants and observers.

2) Validity

To secure the credibility and trustworthiness of the study two types of validity were carefully monitored: Process Validity and Outcome Validity. The process validity involved examination of the adequacy of the processes used in different phases of the action research project [55]. Participants learning design products were reviewed descriptively to identify how they organized the main components of their STEM learning designs. This review focused on key instructional elements: subject topic, learning outcomes, learning activities, STEM integration and assessment strategies. These products were not scored using standardized rubrics. Instead, they were used as supporting evidence to document how participants were applying the workshop materials in their own teaching areas.

To support the credibility of the analysis the outcome validity concentrated on the extent to which actions occurred which led to a resolution of the problem that prompted the emphasis of the action research study [55]. The summaries and interpretations in the following sections were discussed among the authors and checked against the workshop objectives, participant reflections, observer notes and learning design products. This process clarified research bias and helped ensure that the interpretation was grounded in the data collected during the program [56].

E. Ethical Approval and Informed Consent

All studies involving human participants, human data, or animal research complied with international and institutional ethical standards. The Ethics Committee of the Institute for Research and Community Services, Universitas Negeri Jakarta, reviewed the research protocol and granted ethical approval for this study (Approval No. 268/UN39.14/Pt.01.05/III/2026). The committee recommended that the research be carried out by considering the principles stated in the Declaration of Helsinki and the instructions contained in the Research Ethics Guidelines.

All participants signed a consent letter before data collection. The letter of consent included permission to collect research data and to use photographs taken during the workshop for publication purposes. Participants' confidentiality was maintained by reporting the data using participant and observer codes rather than personal names. Personal identifiers were removed from the data used in the analysis and the manuscript and data were accessed only by the research team.

IV. Result and Discussion

Based on participants' reflections they found the workshop both enjoyable and valuable in that it provided them with new insights and practical strategies for teaching and learning. A few representative reflections are included below:

- "Very enjoyable, as it provided new knowledge." (Participant 11, Reflection, 13 August 2024)
- "Gaining new knowledge about how to create a mind map for learning." (Participant 5, Reflection, 15 August 2024)
- "Gave many new insights." (Participant 9, Reflection, 15 August 2024)

Overall, participants indicated that they had gained new knowledge regarding the process of developing learning designs. Particularly the use of mind maps was noted as a helpful strategy to organize various components of instructional planning [20]. They described mind mapping as both interesting and useful for supporting the development of comprehensive learning designs [20]. This finding aligns with Erdem, who emphasized that mind maps are effective tools for organizing thoughts and focusing on specific subjects.

Despite these positive outcomes, participants also reported several challenges. Noted challenges were the difficulty to formulate learning outcomes, design appropriate assessments and implement their learning designs [20]. The distribution of participants who experienced these difficulties is presented in the graph below.

Displayed in Fig. 6, three major difficulties reported by several participants were: determining learning outcomes, designing assessments and implementing the learning design. Specifically, 38.68% of participants indicated difficulties in constructing STEM assessments aligned with learning outcomes. 35.48% struggled with clearly defining learning outcomes. 25.84% reported challenges in implementing the STEM learning design.

Supporting qualitative data from participant reflections are presented below.

- "Formulating learning outcomes along with strategies and

assessment." (Participant 16, Reflection, 13 August 2024)

- "Participants need more time to work on formulating learning outcomes." (Observer 2, Observation Form, 13 August 2024)

The difficulty in formulating learning outcomes also affected the time required to construct comprehensive mind maps.

- "I felt difficulty constructing the components of the mind maps, and it took me a relatively long time to finish." (Participant 15, Reflection, 15 August 2024)

Participants expressed confusion in formulating appropriate learning outcomes and in selecting action verbs that aligned with Bloom's Taxonomy. They reported challenges in ensuring the chosen learning strategies would effectively support the achievement of the intended objectives.

- "I struggled to construct the 'how' of the learning outcomes." (Participant 2, Reflection, 13 August 2024)

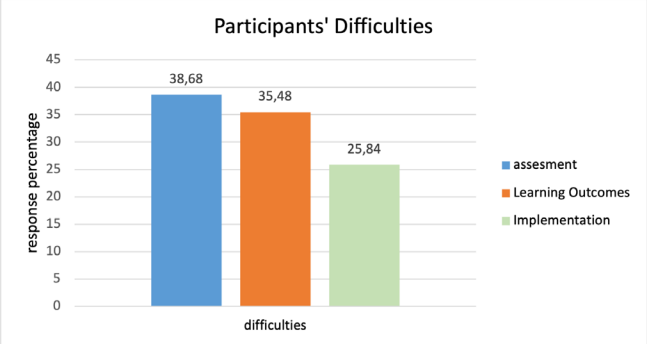


Fig. 6. Percentage of participants' difficulties in three major areas.

In this context, the term 'how' refers to the learning strategy that operationalizes the intended outcome. After identifying the desired outcomes, participants were required to consider the processes by which students could achieve them. Forming learning outcomes in alignment with Bloom's Taxonomy proved challenging as participants demonstrated limited ability to translate their conceptual understanding of the taxonomy levels into practice.

These findings suggest that the use of flashcards was not fully effective in strengthening participants' ability to apply Bloom's Taxonomy in the formulation of learning outcomes. The effectiveness of flashcard use depends on the design of the flashcards and the conditions of the study. Evidence from experimental studies shows that undetailed flashcards used under free-study conditions often yield insignificant effects, as participants may not engage with them deeply enough to achieve meaningful understanding. The outcomes are also influenced by the degree of participant engagement [57].

One of the primary benefits identified by twenty-five of the participants (illustrated in Fig. 7) was an improved understanding of the implementation of the STEM approach. Twenty-four participants stated key benefits they highly valued included the development of STEM teaching competence and the ability to design STEM lesson plans. In addition, twenty-two participants indicated that the workshop facilitated network expansion through connections with lecturers at the Faculty of Mathematics and Natural Sciences. By contrast, only one participant reported that the workshop contributed to cross-departmental collaboration, increased knowledge of education and STEM, or reflections on student perspectives.

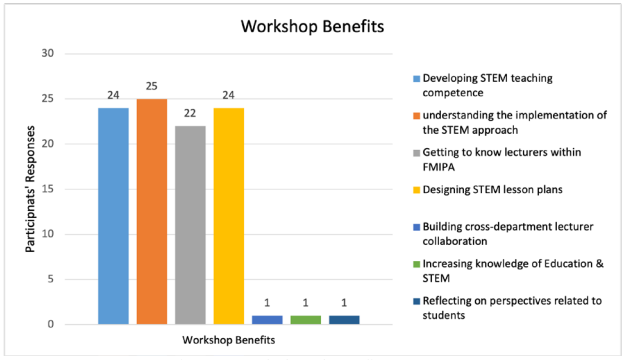


Fig. 7. Workshop benefits reports.

Overall, the findings suggest that the workshop had a considerable impact on participants' conceptual understanding and pedagogical competency development, but a more limited influence on collaboration and reflective teaching practices [20].

- "The experience was highly beneficial, both in terms of the content provided and the interactions with other attendees." (Participant 20, Reflection, 23 August 2024)
- "The Fulbright program on STEM learning enhanced the participants' understanding of how to implement active learning, from lesson planning to assessment." (Participant 9, Reflection, 23 August 2024)

These reflections indicate that participants valued both the content knowledge provided in the workshop and the opportunity for networking with colleagues at the faculty. However, since the projects were designed individually, opportunities for collaboration were limited. Moreover, the unequal distribution of participants across the disciplines of chemistry, biology, mathematics, and physics further constrained the potential for cross-departmental collaboration. This challenge was noted explicitly in the following reflection:

- "I had difficulty collaborating, and I hope that in the future workshop the number of people from each study program will be more proportional." (Participant 21, Reflection, 23 August 2024)

Based on Fig. 8, most participants highlighted two key components as most important for implementing Design-Based Learning (DBL). First, collaboration across STEM disciplines (25 participants) and a strong understanding of STEM subject concepts was deemed necessary. Secondly, twenty-two participants emphasized the importance of understanding the specific courses they taught while 19 participants identified the need to consider the characteristics of students.

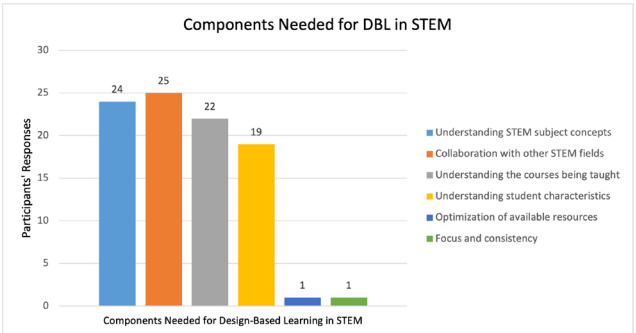


Fig. 8. Component needed for DBL in implementing STEM education.

In contrast, only one participant noted the optimization of available resources, and another emphasized the importance of maintaining consistency and focus. These findings suggest that interdisciplinary collaboration and subject matter mastery are regarded as the primary pillars for the successful implementation of DBL (design-based learning) in STEM education.

These findings align with previous studies emphasizing that interdisciplinary STEM instruction requires strong pedagogical support and opportunities for collaborative, professional learning [15, 19]. Collaborative, professional learning also supported the development of participants' content knowledge and pedagogical knowledge. Difficulties experienced by participants in constructing learning outcomes and assessment strategies reflect broader challenges in STEM curriculum implementation. When educators move from discipline-based instruction toward integrated and inquiry-based learning approaches there is a learning curve for the instructor to overcome to implement active STEM PBL. These challenges are also relevant to their future classroom practices. Therefore, the workshop functioned not only as a training program, but also as a reflective space for participants to reconsider their instructional practices within active learning and STEM integration contexts.

Based on Fig. 9, many participants identified the most important role of teachers as providing constructive feedback for improvement (26 participants) and supporting the development of STEM learning designs. In addition, twenty-four participants emphasized the importance of teachers in encouraging active learning, while twenty-three highlighted the need for teachers to recognize learner characteristics and build positive relationships between instructors and participants. By contrast, only one participant identified the teacher's role in developing new learning concepts as a key element. These findings indicate that instructors were perceived primarily as facilitators of pedagogical guidance and learning design rather than as innovators introducing entirely new conceptual ideas.

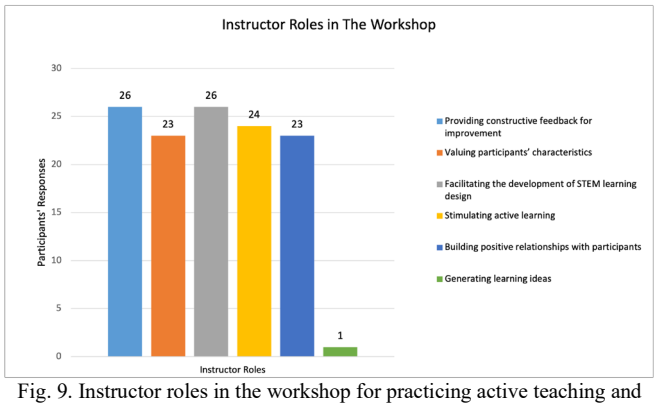


Fig. 9. Instructor roles in the workshop for practicing active teaching and learning.

Representative reflections underscore this perception:

- "Prof. Li-Jen is the best, teaching with genuine effort to ensure all participants understand." (Participant 1, Reflection, 23 August 2024)
- "The instructors were very personable and always appreciated the participants' efforts in carrying out the entire series of workshop activities." (Participant 7, Reflection, 23 August 2024)
- "The instructor visited each group to check their progress and to ensure that the participants had a clear understanding of the material." (Observer 1, Reflection, 13 August 2024)

The percentages reported in figures were calculated based on the number of participants selecting each response category. For questions allowing multiple responses, percentages were calculated based on the total number of responses recorded for the item. The data were derived from participants' workshop reflections and evaluation forms collected during the program evaluation process.

As shown in Fig. 10, Interactions between participants had varying effects on the learning process in the workshop. A total of twenty-four participants stated interacting had helped them collaborate on tasks and communicate ideas effectively. Meanwhile, twenty-two participants stated that interacting with others had helped them understand the workshop material and the same number also stated that interacting had helped them solve problems as a group. These findings showed the interaction between participants influenced the collaboration and communication of ideas. Moreover, active interaction influenced problem solving skills and participants' understanding of the material. The interaction among participants during the workshop facilitated the emergence of new ideas and collaborations in building understanding [58].

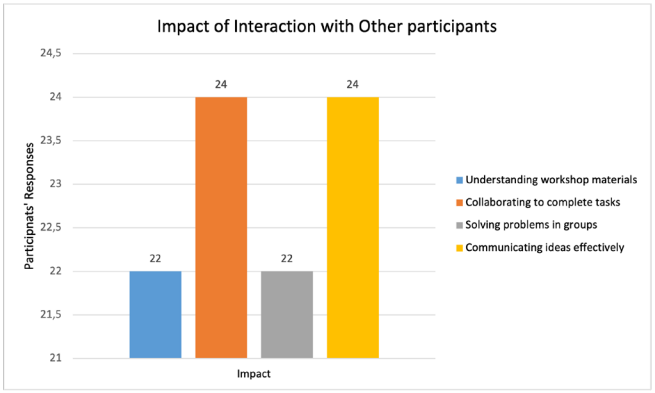


Fig. 10. Impact of interaction with other participants.

Interactions among participants had varied effects on the learning process. During the workshop, as illustrated in Fig. 11, a total of twenty-four participants reported that interaction supported their ability to collaborate on tasks and communicate ideas effectively. In addition, twenty-two participants noted that interacting with others enhanced their understanding of the workshop material and the same number indicated that it facilitated group problem-solving. These findings suggest participant interaction played a significant role in fostering collaboration and idea exchange, while also strengthening problem-solving skills and deepening conceptual understanding. Moreover, active interaction promoted the emergence of new ideas and the construction of knowledge through collaborative engagement [50].

As shown in Fig. 12, twenty-three workshop participants indicated that the procedures introduced were relatively easy to apply within the framework of Design-Based Learning (DBL). Furthermore, eighteen participants noted that each stage of learning could be readily connected to the corresponding assessment stage. Nevertheless, several

challenges remained. Specifically, four participants reported difficulties in linking learning objectives to their respective courses and in developing appropriate assessment instruments. Overall, the findings suggest that while the DBL approach was perceived as practical and feasible to implement, the formulation of learning objectives and the construction of assessment tools continue to require further guidance and support.

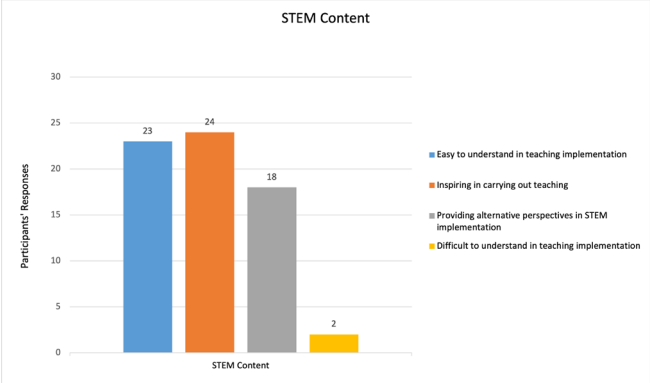


Fig. 11. STEM content acceptances.

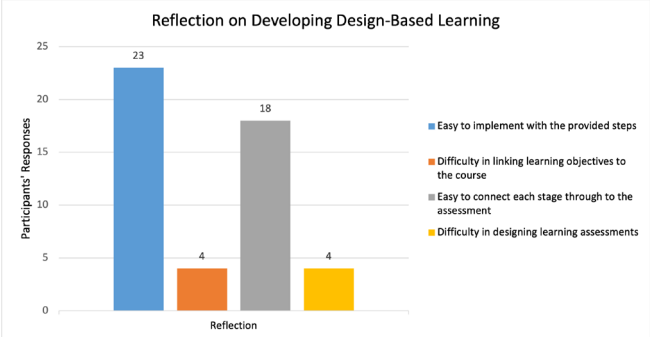


Fig. 12. Reflection on developing design- based learning.

As illustrated in Fig. 13, eleven participants reported that their greatest challenge was identifying appropriate active learning methods. In addition, seven participants noted difficulties in developing instructional designs, while six participants experienced challenges in determining suitable forms of assessment. By contrast, four participants indicated obstacles related to time constraints and lack of motivation, and three participants reported difficulties in selecting the appropriate course content. Only one participant stated that they had not experienced any problems during the workshop. These findings suggest that active learning methodologies and instructional design remain the most pressing issues for participants. Consequently, future workshops should prioritize the development of these areas to better support participants' professional growth.

According to Fig. 14, fourteen participants perceived the microteaching process as relatively easy to implement, primarily because they had already mastered the relevant learning methods. However, several challenges were also identified: eight participants reported difficulties when engaging with content from other STEM disciplines and six participants noted challenges stemming from a lack of confidence. These findings indicate that while mastery of instructional methods was a key factor supporting the effective implementation of microteaching, additional attention is required to address the challenges of cross disciplinary integration and psychological factors such as self-confidence in future activities.

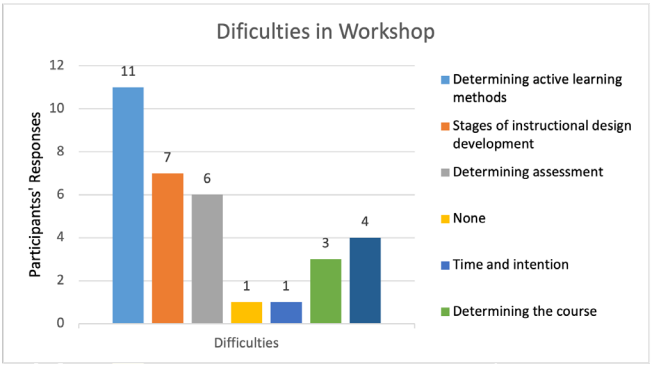


Fig. 13. Identifying difficulties in workshop.

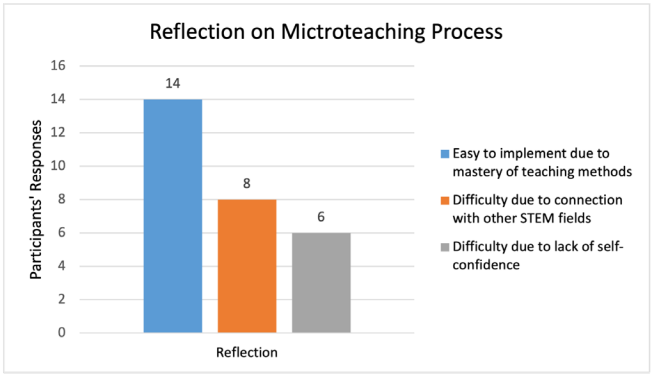


Fig. 14. Reflection on microteaching process.

Based on Fig. 15, twenty-five participants reported that faculty support in scheduling activities was highly beneficial. In addition, twenty-four participants indicated that the workshop equipment provided was adequate for their needs, while twenty-two participants noted that the meals and refreshments also met their expectations. Furthermore, twenty participants agreed that the workshop schedule was appropriately aligned with the objectives of the activity. Overall, these findings suggest that faculty support in terms of facilities, equipment, and logistical arrangements was perceived as sufficient and contributed positively to the successful implementation of the workshop.

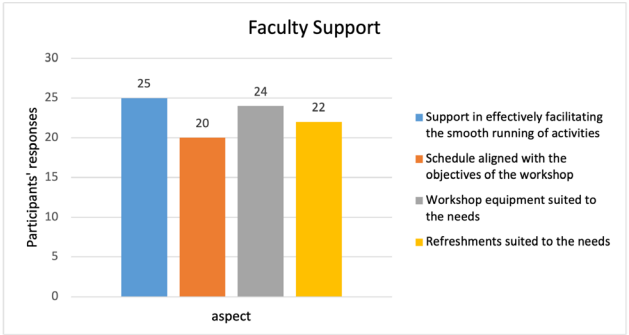


Fig. 15. Faculty support reflection.

The findings highlight the importance of continuous professional development programs that combine conceptual understanding, collaborative curriculum design and practical implementation. Future STEM professional development programs should provide more opportunities for interdisciplinary collaboration, assessment design practice and follow-up implementation activities. Institutional support is also important to strengthen interdisciplinary teaching practices and active learning implementation in higher

education contexts. In addition, as STEM teacher educators, participants also need to understand how STEM learning is implemented in real classroom contexts.

V. Conclusion

The implementation of active learning strategies including collaborative cross-discipline engagement, backward design and concept mapping to redesign undergraduate level STEM courses can and should be considered necessary. This project fulfilled our objectives and demonstrated the desired outcomes for hosting the seminar to increase familiarity with active learning and cross academic disciplines collaboration. It provided an organized course with a clear outline and an easily followed participatory path. The participants experienced active learning strategies for formative assessment, increased student engagement, improved communication and provided students with an opportunity to reflect on their understanding. In addition, the participants recognized concise learning objectives, reflective assessment tools, and efficiently arranged course materials which were constructively aligned to help identify redundant materials and eliminate irrelevant topics. Moreover, the backward design method proved to provide students with a better understanding of the learning expectations for the entirety of the course.

This project found that this Fulbright Specialist workshop supported STEM lecturers' understanding of active learning, backward design, and interdisciplinary STEM learning design. Participants reported increased confidence in developing STEM lesson plans and appreciated opportunities for collaboration and feedback. However, challenges remained in formulating learning outcomes, constructing aligned assessments, and implementing interdisciplinary STEM instruction. These findings should be considered within the limitations of a small-scale program evaluation conducted at a single institution with a relatively small participant group and reliance on self-reported reflections. Future research could examine long-term implementation of STEM learning designs, include classroom observation data, and explore comparative studies across institutions.

This project accomplished providing global resources to support STEM education by implementing innovative teaching and learning strategies within interdisciplinary approaches. The research hypothesis was proven true in that two weeks of implementation from the Fulbright Specialist Workshop was needed and adequate to build a strong competence of STEM educators creating innovative strategies in their teaching and learning practices.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All listed authors conducted portions of the research and contributed to the writing of the paper. Li-Jen Y. Lester, Yuli Rahmawati, and Dewi Muliyati refined the paper. Talitha Erinna, Lauzer Zeral, and Dewi Muliyati collected images, conducted data analysis, and wrote the data analysis section. Bruce W. Lester edited the entire paper. All authors approved the submission version. In the end, Bruce W. Lester completed the final editing.

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