



The Chemistry of Leadership: Integrating STEAM and Experiential Learning to Enhance Student Leadership Skills

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ABSTRAK

The development of leadership skills among junior high school students is an essential component of 21st-century character education. However, many school-based programs remain conventional and lack contextual learning experiences that integrate academic knowledge with social competencies. This community engagement initiative, conducted by the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman, aimed to enhance students' leadership, communication, collaboration, and problem-solving skills through The Chemistry of Leadership Camp: Explore, React, Lead!. The program was implemented in two phases. The first phase, conducted at Berambai Waterfall, focused on leadership development through outdoor experiential learning involving 30 student council members. The second phase, conducted at SMPN 42 Samarinda, aimed to strengthen students' character based on the eight dimensions of the graduate profile through talent showcase and reflective activities. The program applied experiential learning integrated with scientific simulations and STEAM-based collaboration. The results showed a significant improvement in leadership understanding, with mean scores increasing from 62.5 to 88.3, and correct response rates rising from 62.2% to 91.1%. Chemical analogies effectively supported conceptual understanding. Overall, this model offers an innovative and replicable approach to leadership and character education

INTRODUCTION

The transformation of 21st-century education demands learning systems that extend beyond the acquisition of academic knowledge to include the development of essential competencies such as leadership, communication, collaboration, creativity, and critical thinking (Trilling & Fadel, 2021). These competencies serve as a fundamental foundation for preparing young generations to navigate increasingly complex global challenges, including rapid technological advancement, evolving social dynamics, and future workforce demands (World Economic Forum, 2020; Bass, B. M., & Riggio, R. E. 2021).

At the junior high school level, early adolescence represents a critical stage in the formation of personal identity and social character. During this phase, individuals begin to develop the ability to interact within groups, make decisions, and lead social activities (Santrock, 2018). Therefore, leadership education should be integrated into both formal learning processes and extracurricular activities.

One of the primary platforms for student leadership development in schools is the student council organization (OSIS), which functions as a medium for learning democratic values, organizational management, and social responsibility. However, previous studies indicate that leadership training activities in schools are often administrative and ceremonial in nature, thus lacking meaningful and transformative learning experiences (Dugan & Komives, 2019; Seemiller & Grace, 2020).

Experiential learning has emerged as an effective approach for developing students' leadership skills. This approach emphasizes learning through direct experience, reflection, conceptualization, and application in real-world contexts (Kolb, 2015). Through hands-on activities and reflective discussions, students can more effectively develop communication skills, teamwork, and decision-making abilities (Leithwood, K., Harris, A., & Hopkins, D. 2020).

In addition, integrating scientific concepts into leadership learning represents an innovative direction in modern education. The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach enables students to understand the relationship between scientific concepts and real-life social phenomena (Yakman & Lee, 2012; Perignat & Katz-Buonincontro, 2019). In this context, chemical principles—such as reactions, energy changes, catalysis, and equilibrium—can be used as metaphors to explain leadership dynamics and team interactions.

SMPN 42 Samarinda is one of the schools with active student organizational activities. However, initial observations and discussions with teacher advisors indicated that students require more innovative, practical, and contextual leadership training. Additionally, the school's proximity to the natural environment of Berambai provides an opportunity to implement outdoor learning activities that support character development.

Based on these considerations, the community service team from the Chemistry Study Program, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman developed The Chemistry of Leadership Camp: Explore, React, Lead! as a science-based and experiential leadership training

model. This program integrates chemical concepts as leadership metaphors with outdoor activities emphasizing collaboration, communication, and problem-solving.

The objectives of this program were to enhance students' understanding of adaptive leadership, develop communication and collaboration skills, and strengthen their confidence in leading school activities. Additionally, the program supports the implementation of character education through the reinforcement of the Pancasila student profile, including independence, cooperation, creativity, and critical thinking (Kemendikbudristek, 2022). This study offers a novel interdisciplinary approach by integrating chemical concepts as pedagogical metaphors for leadership development within a STEAM-based experiential learning framework

IMPLEMENTATION AND METHOD

Program Design

This community engagement program employed an experiential learning approach integrated with STEAM-based instructional strategies. The approach emphasizes learning through direct experience, reflection, and group discussion to enhance both conceptual understanding and social competencies.

Location and Participants

The program was conducted in October 2025 at two locations: the Berambai Waterfall area and SMPN 42 Samarinda. The participants consisted of 30 students who were members of the school's student council (OSIS) and all the students

Training Module Development

Based on the needs analysis, a chemistry-based leadership training module was developed, incorporating the following concepts:

1. Synthesis reactions as a representation of teamwork collaboration
2. Exothermic and endothermic reactions as analogies for emotional energy dynamics
3. Catalysts as a representation of leadership roles in accelerating change
4. Chemical equilibrium as a model for balanced decision-making

Leadership Camp Implementation

The program was implemented in three main phases:

- **Explore:** Focused on self-awareness and identifying individual leadership potential through educational games and group discussions.
- **React:** Emphasized teamwork and problem-solving through simulations and simple experiments illustrating chemical reaction dynamics.
- **Lead:** Focused on the application of leadership skills through mini-projects, group presentations, and performance activities.

Evaluation Methods

Evaluation was conducted using:

1. **Quantitative assessment** through pre-post tests
2. **Qualitative evaluation** through observations, documentation, and group reflections

RESULTS AND DISCUSSION

The implementation of the Leadership Camp demonstrated that integrating experiential learning with STEAM-based approaches provides a meaningful and engaging learning experience. Students showed increased participation, improved collaboration, and enhanced confidence in expressing ideas. First, from the standpoint of experiential learning theory, the structured progression of activities in the Explore–React–Lead model aligns closely with the learning cycle proposed by Kolb (2014), which includes concrete experience, reflective observation, abstract conceptualization, and active experimentation.

The Explore phase facilitated self-awareness and reflection, enabling students to recognize their personal strengths and leadership tendencies. This aligns with the notion that self-awareness constitutes a foundational element of effective leadership development (Northouse, 2022). The React phase provided concrete experiences through collaborative problem-solving tasks, while the Lead phase allowed students to actively experiment with leadership roles in real-world contexts. Such alignment with the experiential learning cycle likely contributed to the deeper internalization of leadership concepts observed in this study.

Second, the use of chemical analogies as instructional metaphors can be interpreted through the lens of constructivist learning theory. According to constructivist principles, learners actively construct knowledge by connecting new information with prior cognitive frameworks. The analogical mapping between chemical processes, such as synthesis reactions, catalysis, and equilibrium and leadership dynamics appears to have facilitated conceptual understanding by providing familiar and structured representations of abstract social phenomena.

This is consistent with prior research suggesting that analogical reasoning enhances the comprehension of complex concepts by bridging abstract and concrete domains (Nichols. & Cator, 2021). In this context, the chemistry-based metaphors functioned not merely as illustrative tools but as cognitive scaffolds that supported meaningful learning. Third, the STEAM-based integration adopted in this program contributes to the development of higher-order thinking skills, particularly critical thinking, creativity, and problem-solving.

The interdisciplinary nature of STEAM learning encourages students to approach problems from multiple perspectives, thereby fostering cognitive flexibility (Bybee, 2019; Margot & Kettler, 2022). In this study, students were required to interpret scientific analogies, engage in collaborative tasks, and design solutions to contextual problems, all of which are indicative of higher-order cognitive engagement. This may explain the significant improvement in students' ability to understand and apply leadership concepts beyond rote memorization.

In addition, the collaborative dimension of the program plays a critical role in shaping leadership competencies. Social constructivist theory emphasizes that learning is inherently a social process, mediated through interaction and shared experiences. The group-based activities implemented during the React and Lead phases provided opportunities for peer interaction, negotiation of meaning, and

collective decision-making. These processes are essential for the development of communication skills, empathy, and shared responsibility –key attributes of effective leadership. The observed increase in students’ participation and engagement during group discussions further supports the effectiveness of this collaborative learning environment.

The implementation of this community engagement program was carried out in two main settings, each designed to support different aspects of leadership development (Figure 1). The first phase took place at Berambai Waterfall, where outdoor-based leadership activities were conducted. This natural environment provided an authentic and experiential learning context that encouraged students to develop teamwork, communication, and problem-solving skills through interactive group challenges. The use of outdoor settings is known to enhance student engagement and promote active participation, as learners are directly involved in real-life situations that require collaboration and adaptive decision-making.



Figure 1. Leadership Training Activities Conducted at Berambai Waterfall through Outdoor Experiential Learning

The second phase was conducted at SMPN 42 Samarinda and focused on talent showcase activities as part of the “Lead” stage of the program (Figure 2). In this session, students were given the opportunity to express their creativity, demonstrate their leadership potential, and apply the skills acquired during the camp through performances and group presentations. This activity not only strengthened students’ self-confidence but also reinforced their ability to communicate ideas effectively and work collaboratively within a team.



Figure 2. Talent Showcase Activities Conducted at SMPN 42 Samarinda during the “Lead” Stage of the Program.

Quantitative results indicated a substantial improvement in leadership understanding, with average scores increasing from 62.5 to 88.3 (Figure 3). The percentage of correct responses also improved significantly from 62.2% to 91.1% (Figure 4).

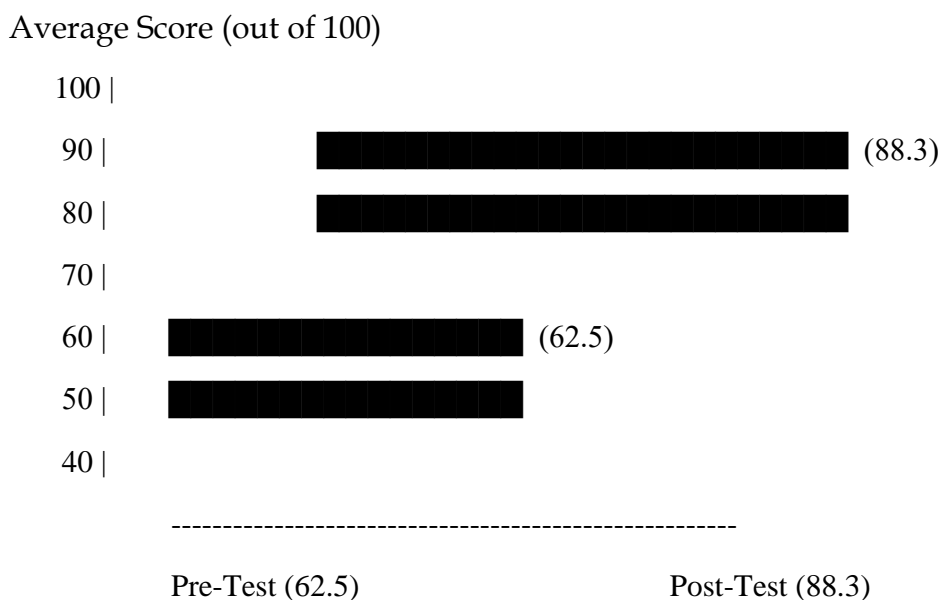


Figure 3. Improvement in Students' Average Leadership Scores before and after the Implementation of the Program, Showing an Increase of 25.8 Points.

These findings confirm that experiential learning, combined with scientific analogies, effectively enhances students' conceptual understanding and engagement. The results are consistent with previous studies highlighting the effectiveness of experiential and STEAM-based learning approaches in developing critical thinking, collaboration, and leadership skills. Furthermore, this study demonstrates that the integration of experiential learning with a chemistry-based STEAM approach provides a meaningful and effective framework for developing leadership competencies among junior high school students. The observed improvement in students' leadership understanding, as reflected by the substantial increase in post-test scores, can be theoretically explained through several complementary perspectives.

Figure 4 was the percentage of correct responses for each question before and after the implementation of the Chemistry of Leadership Camp, revealing a consistent and substantial improvement across all assessed concepts. Overall, the average percentage of correct answers increased from 62.2% in the pre-test to 91.1% in the post-test, representing a gain of 28.9%. This result indicates a significant enhancement in students' conceptual understanding of leadership-related topics following the intervention.

A closer examination of individual items shows that the highest improvement was observed in Question 6 (Camp Stages: Explore, React, Lead), with an increase of 40%. This suggests that the structured experiential learning framework was highly effective in helping students internalize the stages of the program. The clear progression of activities likely reinforced their understanding

through repeated exposure and practical application, aligning with the principles of experiential learning theory.

Similarly, substantial gains were recorded in Question 11 (Talent Showcase Objectives - Activity) and Question 3 (Reaction Analogies), with improvements of 37% and 34%, respectively. These findings highlight the effectiveness of integrating chemistry-based analogies into leadership learning. The use of scientific metaphors appears to have facilitated conceptual transfer, allowing students to better grasp abstract leadership concepts through familiar scientific frameworks.

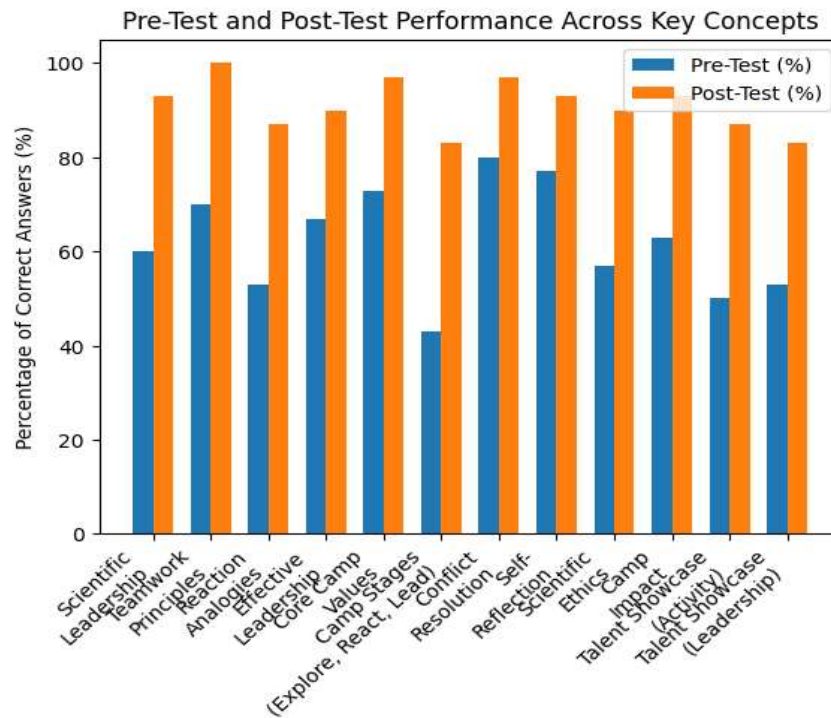


Figure 4. Presents the Percentage of Correct Responses for Each Question before and after the Implementation of the Chemistry of Leadership Camp

Moderate improvements were observed in areas such as Scientific Leadership (33%), Scientific Ethics (33%), and Teamwork Principles (30%). These results indicate that the program not only strengthened cognitive understanding but also reinforced values and principles associated with effective leadership. The relatively high post-test scores in these areas suggest that students were able to connect theoretical concepts with practical experiences during the camp.

In contrast, smaller yet still meaningful gains were observed in Question 7 (Conflict Resolution, +17%) and Question 8 (Self-Reflection, +16%). These lower increases may be attributed to the relatively high baseline scores in the pre-test, indicating that students already possessed some prior understanding of these concepts. Nevertheless, the improvement observed suggests that the program contributed to refining and deepening their existing knowledge.

Overall, the consistent improvement across all items demonstrates that the combination of experiential learning and a STEAM-based approach is effective in enhancing students' understanding of leadership concepts. The integration of

collaborative activities, reflective exercises, and chemistry-based analogies appears to have created a comprehensive learning environment that supports both cognitive and socio-emotional development.

These findings are consistent with previous studies indicating that experiential learning enhances conceptual understanding and student engagement, while interdisciplinary approaches such as STEAM foster critical thinking and problem-solving skills. From a motivational perspective, the incorporation of outdoor and context-based learning activities likely contributed to increased student engagement. Self-determination theory posits that intrinsic motivation is enhanced when learners experience autonomy, competence, and relatedness (Nichols, M., & Cator, K. (2021).

The program design allowed students to actively participate in decision-making processes, demonstrate their abilities, and interact meaningfully with peers, thereby fulfilling these psychological needs. This may explain the high level of enthusiasm and active involvement observed during the program. Despite these positive findings, several limitations should be acknowledged. First, the study employed a relatively small sample size and was conducted within a single institutional context, which may limit the generalizability of the results.

Second, the evaluation relied primarily on short-term assessments, making it difficult to determine the long-term impact of the intervention on students' leadership development. Future research should consider longitudinal designs and larger sample sizes to validate and extend these findings. Nevertheless, this study offers important contributions to the field of educational innovation and leadership development.

It provides empirical evidence that integrating scientific concepts into leadership training through experiential and STEAM-based approaches can enhance both cognitive and socio-emotional competencies. Furthermore, the use of chemistry as a metaphorical framework represents a novel pedagogical strategy that bridges disciplinary boundaries and enriches students' learning experiences.

In conclusion, the Chemistry of Leadership Camp demonstrates that interdisciplinary, experience-based learning models can serve as powerful tools for developing leadership skills in secondary education. The approach not only strengthens conceptual understanding but also fosters essential 21st-century competencies, positioning it as a promising model for broader implementation in educational practice.

CONCLUSION AND RECOMMENDATIONS

The Chemistry of Leadership Camp program significantly improved the leadership skills of students at SMPN 42 Samarinda. The integration of experiential learning with chemistry-based analogies proved effective in enhancing students' understanding of leadership dynamics and teamwork. The findings indicate that this science-based leadership training model offers an innovative approach to character education and holds strong potential for replication in other educational contexts.

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