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Article

Integrating Sustainability into Vocational High School Department of Fowl and Livestock Health Care: The Role of Teacher Leadership in Enhancing Student Learning Effectiveness in Taiwan

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Abstract: This study investigates the influence of teacher leadership on student learning outcomes within practice-oriented professional curricula in Taiwan's vocational high schools, specifically focusing on the Department of Fowl and Livestock Health Care. The research addresses a critical gap in understanding how vocational education can effectively contribute to sustainable agricultural practices, a pressing concern given global challenges in food security, climate change mitigation, and environmental stewardship. Situated within the broader framework of the United Nations Sustainable Development Goals (SDGs)—particularly SDG 4 (Quality Education) and SDG 2 (Zero Hunger)—the study highlights the necessity of equipping future agricultural professionals with the knowledge, skills, and attitudes to pursue sustainable and resilient agricultural development. Employing a rigorous methodological approach, data were collected through a stratified proportional random sampling technique involving 500 vocational high school students. A structured questionnaire assessed student perceptions across six key dimensions of teacher leadership, namely charismatic influence, motivational encouragement, intellectual stimulation, individualized care, contingent rewards, and management by exception. Additionally, student learning effectiveness was measured through three dimensions: professional cognition, engagement in practical learning activities, and group interactions. Comprehensive statistical analyses—including independent t-tests, one-way ANOVA with Scheffé's post-hoc comparisons, and Pearson correlation analyses—were performed to explore the relationships among these variables. The implications of these findings are substantial for educational policy and practice, underscoring the importance of targeted teacher leadership training programs designed to enhance vocational educators' capacity to foster sustainability-oriented competencies among students. This research advocates for the explicit integration of sustainability principles into vocational curricula and instructional strategies, positioning teacher leadership as an essential mechanism for achieving sustainable agricultural transformation and developing a workforce capable of addressing contemporary and future environmental and food-security challenges.

Keywords: teacher leadership; student learning effectiveness; vocational education; practice-oriented curriculum; sustainable development; agricultural transformation

1. Introduction

1.1. Background and Context

Global challenges such as climate change, food insecurity, and the urgent need for sustainable development are driving profound changes in agricultural practices worldwide [1,2]. In Taiwan, these challenges have spurred efforts to modernize the agricultural sector by integrating innovative technologies and sustainable practices [3], aiming to enhance both productivity and environmental stewardship. Vocational education is now recognized as a pivotal component in this transformation [4],

as it equips future professionals [5] with the practical skills and critical knowledge necessary to implement sustainable agricultural practices [6]. This study is set against this backdrop, where the interplay between quality education and sustainable development has become a strategic imperative for national progress [7,8]. Furthermore, the evolving global agenda on sustainability demands that educational institutions not only focus on technical training but also instill a deep sense of environmental responsibility and innovation among their students [9,10].

In addition to these external pressures, internal dynamics within the agricultural sector in Taiwan highlight the need for a new generation of professionals who can navigate the complexities of modern [11], sustainable agriculture. The transformation of traditional practices into more efficient and eco-friendly systems requires a skilled workforce that is capable of implementing advanced techniques in animal health care and smart livestock management [12]. This context underscores the importance of integrating sustainability into vocational training programs [13], thereby ensuring that graduates are well-prepared to contribute to long-term agricultural resilience and food security [14].

1.2. Vocational Education in the Department of Fowl and Livestock Health Care

Vocational high schools in Taiwan have long served as critical institutions for cultivating specialized skills, particularly within the Department of Fowl and Livestock Health Care [15]. These programs are meticulously designed to bridge theoretical knowledge with extensive practical training [16], providing students with hands-on experiences that are directly relevant to industry demands. Given the vital role of animal health care in ensuring food safety and enhancing agricultural productivity, the quality of vocational education in this field is indispensable [17]. By focusing on practice-oriented curricula, these programs not only address immediate technical competencies but also foster an innovative mindset essential for sustainable agricultural transformation [18,19].

Moreover, the rapid evolution of agricultural technologies and market dynamics has underscored the need for continuous curriculum innovation [20]. As vocational education adapts to these changes, it increasingly emphasizes the integration of sustainable practices within its teaching frameworks [21]. In the Department of Fowl and Livestock Health Care, this means incorporating modern management techniques, biosecurity measures, and environmentally friendly practices into everyday instruction. This dual focus on technical excellence and sustainability ensures that graduates are not only capable practitioners but also conscientious stewards of natural resources, ready to meet the challenges of a transforming agricultural landscape.

1.3. Teacher Leadership in Practice-Oriented Curricula

Teacher leadership plays a crucial role in shaping the learning environment in practice-oriented curricula [22]. In vocational settings, effective teacher leadership transcends traditional instructional roles by actively engaging students, inspiring innovative thinking, and fostering a supportive classroom culture [23]. This study examines several dimensions of teacher leadership, including charismatic influence, motivational encouragement, intellectual stimulation, individualized care, contingent rewards, and management by exception [24]. Each of these aspects contributes uniquely to creating a dynamic and effective learning environment, where teachers act as facilitators and mentors guiding students toward professional excellence [25].

In such settings, the teacher's role evolves into a multifaceted one that not only imparts knowledge but also models best practices [26], motivates students to overcome challenges, and promotes a culture of continuous improvement [27]. By adopting diverse leadership strategies, teachers can enhance student engagement, foster critical thinking, and facilitate the practical application of skills [28]. This research investigates how these leadership practices are perceived by students and how they correlate with measurable improvements in learning outcomes, thereby providing insights into the essential factors that drive success in vocational education.

1.4. Student Learning Effectiveness and Professional Outcomes

Student learning effectiveness in practice-oriented educational settings encompasses a range of cognitive, behavioral, and interpersonal outcomes [29,30]. In this study, learning effectiveness is evaluated across three primary dimensions: professional cognition, learning activities, and group interactions. Professional cognition reflects students' ability to understand and apply specialized knowledge; learning activities measure their engagement and participation in practical tasks; and group interactions assess their capacity for collaboration and communication. This comprehensive approach allows for a nuanced examination of how effective teacher leadership translates into enhanced student performance and overall professional readiness.

The outcomes of such evaluations are critical, as they not only determine the immediate success of educational programs but also have long-term implications for workforce development in the agricultural sector. Students who benefit from strong instructional leadership are more likely to excel in their professional roles, thereby contributing to the broader goals of sustainable agricultural transformation. This study, therefore, provides valuable evidence on the link between teacher leadership and learning effectiveness, offering actionable insights for improving vocational training strategies.

1.5. Methodological Overview and Research Focus

To rigorously examine the relationship between teacher leadership and student learning effectiveness [31], this study employed a stratified proportional random sampling method to collect data from 500 valid responses from vocational high school students in the Department of Fowl and Livestock Health Care. The survey instrument, which was developed through an extensive review of relevant literature and validated by field experts, measures six dimensions of teacher leadership and three dimensions of student learning effectiveness. Quantitative analyses were conducted using independent t-tests, one-way ANOVA with Scheffé's post-hoc comparisons, and Pearson's correlation analysis to assess the interrelations among these dimensions.

This methodological framework ensures that the findings are robust and reflective of the complex dynamics within vocational education. By systematically analyzing the data, the study identifies key trends and differences among various student groups, such as variations based on grade level, regional distribution, and the number of certified academic portfolios. Such detailed insights help clarify the mechanisms through which teacher leadership influences learning outcomes and support the development of targeted educational interventions.

1.6. Sustainability and Educational Implications

Aligning with the Sustainable Development Goals, particularly SDG 4 (Quality Education) and SDG 2 (Zero Hunger) [32], this study underscores the role of vocational education as a driver of sustainable development in the agricultural sector. Effective teacher leadership is not only a determinant of academic success but also a catalyst for instilling sustainable practices among future professionals. By integrating sustainability into the curriculum, vocational high schools can produce graduates who are well-equipped to implement innovative and environmentally responsible strategies in fowl and livestock health care.

The implications of this research extend well beyond the classroom. The findings offer practical recommendations for education policymakers and curriculum designers, emphasizing the importance of incorporating sustainability principles into teaching practices. By doing so, educational institutions can enhance learning effectiveness, support the transition to sustainable agricultural practices, and ultimately contribute to a resilient and sustainable food system [33]. This study provides a compelling argument for reimagining vocational education as a key element in the broader sustainability agenda, ensuring that future professionals are capable of addressing the multifaceted challenges of modern agriculture [34].

2. Materials and Methods

2.1. Participants

The study targeted the entire population of students enrolled in the Department of Fowl and Livestock Health Care at vocational high schools in Taiwan during the 111 academic year. A total of 1,479 students across 15 schools constituted the sampling frame, ensuring that the sample was representative of various educational settings and regional contexts. The schools were stratified into three distinct regional groups—Northern, Central, and Southern/Eastern—to capture potential differences in resource allocation, local educational practices, and demographic characteristics. This stratification allowed the study to compare and contrast the perceptions of teacher leadership and student learning effectiveness across diverse environments. The sampling method, a stratified proportional random sampling technique, was employed to ensure that each subgroup was proportionately represented, which is critical for drawing reliable and generalizable conclusions from the data.

2.2. Instrument Development and Validation

The primary data collection instrument was a self-developed questionnaire, designed to comprehensively assess the constructs of teacher leadership and student learning effectiveness in the context of practice-oriented professional curricula. The questionnaire was structured into three sections: the first section gathered demographic and background information (including gender, grade level, school region, certification status, competition experience, and the number of certified learning portfolio items); the second section measured teacher leadership style through 24 items covering six dimensions—charismatic influence, motivational encouragement, intellectual stimulation, individualized care, contingent rewards, and management by exception; and the third section evaluated student learning effectiveness via 21 items focusing on professional cognition, learning activities, and group interactions. The instrument was developed after an extensive review of the literature and was refined through consultations with subject-matter experts. This iterative process of item formulation, expert review, and pilot testing ensured that the questionnaire not only possessed strong content validity but was also contextually appropriate for the target population.

2.3. Pretest Procedures

Prior to the formal survey, a pretest was conducted to evaluate the clarity, reliability, and validity of the questionnaire. A pilot sample of 150 students was selected using the same stratified proportional random sampling approach and administered the preliminary version of the questionnaire over a one-month period in March 2023. The pretest involved rigorous item analysis, where each question was evaluated for its discriminative power by calculating Critical Ratio (CR) values and Pearson correlation coefficients between individual items and the overall scale scores. Items that did not achieve statistical significance at the 0.05 level or did not enhance the overall reliability (as indicated by an increase in Cronbach's alpha upon deletion) were revised or removed. The pretest confirmed high internal consistency with Cronbach's alpha values of 0.975 for the teacher leadership scale and 0.965 for the student learning effectiveness scale. These results allowed for minor modifications before finalizing the questionnaire for the formal survey.

2.4. Formal Survey Administration

Following the successful pretest, the finalized questionnaire was administered as the formal survey between April 1 and May 31, 2023. A total of 515 questionnaires were distributed across 10 randomly selected schools from the stratified sample, ensuring broad coverage and representation of different regions. Distribution methods included both in-person administration and electronic dissemination (via email and telephone follow-ups) to maximize the response rate. Extensive efforts were made to secure cooperation from school administrators and teachers, who assisted in coordinating the distribution and collection of the questionnaires. Out of the 515 distributed questionnaires, 509 were returned. After a careful screening process to remove incomplete or inconsistent responses, 500

valid questionnaires were retained, resulting in an effective response rate of 97.1%. The high response rate contributes to the reliability and generalizability of the study findings.

2.5. Data Analysis Techniques

The data collected were systematically coded and entered into SPSS for comprehensive statistical analysis. Descriptive statistics were first employed to summarize the demographic characteristics of the participants and to compute the means and standard deviations for each dimension of teacher leadership and student learning effectiveness. To test the research hypotheses, independent t-tests were used for binary comparisons (e.g., gender and competition experience), while one-way analysis of variance (ANOVA) was utilized for variables with more than two categories (e.g., grade level, school region, certification status, and the number of learning portfolio items). When ANOVA results indicated significant differences, Scheffé's post-hoc tests were conducted to identify specific group differences. Furthermore, Pearson's product-moment correlation analysis was carried out to explore the relationships between teacher leadership styles and student learning effectiveness. All statistical tests were conducted at a significance level of $\alpha = 0.05$, ensuring that the findings are both statistically and practically meaningful.

2.6. Ethical Considerations

Prior to the commencement of the study, ethical approval was obtained from the relevant institutional review board to ensure that all research activities met the highest ethical standards. All participants were fully informed about the purpose, procedures, and potential risks associated with the study, and they provided written informed consent prior to participation. The study guaranteed that participation was entirely voluntary, and respondents were assured of their right to withdraw from the study at any point without any adverse consequences. Confidentiality and anonymity were strictly maintained by assigning unique codes to each questionnaire and securely storing the data in password-protected files. These ethical safeguards ensured that the study adhered to international ethical standards and that the rights and welfare of the participants were fully protected throughout the research process.

3. Results

3.1. Sample Characteristics

The study sample consisted of 500 valid responses drawn from a total population of 1,479 students enrolled in the Department of Fowl and Livestock Health Care at vocational high schools in Taiwan during the 111 academic year. Using a stratified proportional random sampling method, participants were carefully selected from 15 schools across three distinct geographical regions (North, Central, and South/East) to ensure that the sample accurately reflected the diverse educational contexts in the country. This stratification was critical not only to capture variations in demographic characteristics but also to examine how regional differences might influence the perceptions of teacher leadership and student learning outcomes. In addition to basic demographic information such as gender and grade level, the questionnaire also captured data on certification status, competition experience, and the number of certified learning portfolio items. Table 1 summarizes the background variables, which form the foundation for subsequent subgroup analyses and provide essential context for interpreting the study's main findings.

Table 1. Descriptive statistics for the sample background variables.

Variable	Category	Frequency	Percentage (%)
Gender	Male	210	42.0
	Female	290	58.0
Grade	1st Year	196	39.2
	2nd Year	176	35.2
	3rd Year	128	25.6
Region	North	153	30.6
	Central	170	34.0
	South/East	177	35.4
Certification	0 Certificates	302	60.4
	1 Certificate	130	26.0
	2 Certificates	62	12.4
	3+ Certificates	6	1.2
Competition Experience	None	438	87.6
	1 Time	40	8.0
	2+ Times	22	4.4
Learning Portfolio	0 Items	136	27.2
	1 Item	62	12.4
	2 Items	87	17.4
	3+ Items	215	43.0

The demographic data reveal a balanced and diverse sample, with slight female predominance, which is consistent with trends in vocational education for this field. The nearly equal regional distribution supports robust comparisons across different geographic areas. This detailed characterization of the sample not only enhances the credibility of the study but also sets the stage for exploring the relationships between demographic factors, teacher leadership, and student learning outcomes.

3.2. Teacher Leadership Scale Results

The teacher leadership scale, which includes 24 items covering six distinct dimensions, was designed to capture the multifaceted nature of effective instructional leadership within a practice-oriented curriculum. These dimensions are: Charismatic Influence, Motivational Encouragement, Intellectual Stimulation, Individualized Care, Contingent Rewards, and Management by Exception. As shown in Table 2, the highest mean score was recorded for Charismatic Influence (M = 4.14, SD = 0.873), indicating that students generally perceive their instructors as having a strong, inspiring presence. The remaining dimensions yielded mean scores that consistently ranged between 3.87 and 3.99, suggesting that while students recognize effective leadership practices, there is room for further enhancement in areas such as individualized care and contingent rewards. The overall teacher leadership score of 3.96 (SD = 0.816) reflects a general agreement that the teachers’ leadership behaviors positively contribute to the learning environment.

Table 2. Summary of teacher leadership dimensions.

Dimension	No. of Items	Mean	SD
Charismatic Influence	4	4.14	0.873
Motivational Encouragement	4	3.93	0.895
Intellectual Stimulation	4	3.94	0.895
Individualized Care	4	3.87	0.924
Contingent Rewards	4	3.91	0.848
Management by Exception	4	3.99	0.873
Overall (Teacher Leadership)	24	3.96	0.816

These findings underscore the complex and layered nature of teacher leadership in vocational high school settings. The relatively high score for Charismatic Influence suggests that teachers are successful in engaging students through their personal appeal and presence. Meanwhile, the dimensions of Motivational Encouragement and Intellectual Stimulation, though slightly lower, indicate that there is a clear recognition of the teachers’ efforts to promote a dynamic and interactive classroom. Such insights are valuable for both educational researchers and practitioners seeking to refine leadership strategies that foster enhanced learning outcomes.

3.3. Student Learning Effectiveness Scale Results

The student learning effectiveness scale, consisting of 21 items distributed over three dimensions—Professional Cognition, Learning Activities, and Group Interaction—was used to evaluate the extent to which students feel that the curriculum has contributed to their professional development and practical skill acquisition. Table 3 presents the descriptive statistics for these dimensions. The highest mean score was observed in the Professional Cognition dimension (M = 4.16, SD = 0.764), suggesting that students perceive a strong alignment between the curriculum and the acquisition of relevant theoretical and practical knowledge. Meanwhile, the scores for Learning Activities and Group Interaction were slightly lower (M = 4.07 and 4.08, respectively), yet still reflect positive student evaluations of active participation and collaborative learning experiences. The overall learning effectiveness score of 4.10 (SD = 0.766) demonstrates that students generally agree the practice-oriented curriculum is effective in preparing them for future professional challenges.

Table 3. Summary of student learning effectiveness dimensions.

Dimension	No. of Items	Mean	SD
Professional Cognition	7	4.16	0.764
Learning Activities	7	4.07	0.824
Group Interaction	7	4.08	0.807
Overall (Learning Effectiveness)	21	4.10	0.766

The data suggest that the curriculum is successful in fostering a high level of professional competence among students, particularly in their ability to understand and integrate complex subject matter. The moderately high scores in Learning Activities and Group Interaction further illustrate that the curriculum promotes not only individual academic growth but also collaborative skills that are essential in professional settings. These outcomes serve as a strong indicator of the curriculum’s overall effectiveness in bridging the gap between theory and practice.

3.4. Group Comparisons for Teacher Leadership

In order to explore potential differences in the perception of teacher leadership, the study conducted group comparisons using independent sample t-tests and one-way ANOVA. Initial comparisons based on gender indicated no statistically significant differences in the overall teacher leadership scores between male and female students ($t = -0.263$, $p = 0.792$), suggesting that gender does not influence the perception of leadership practices within this educational context. However, when comparing across grade levels, significant differences emerged. As shown in Table 4, third-year students (M = 4.28, SD = 0.783) reported significantly higher perceptions of teacher leadership than second-year students (M = 3.96, SD = 0.976), indicating that prolonged exposure to the curriculum may enhance students’ appreciation of effective leadership.

Table 4. ANOVA results for teacher leadership by grade level.

Grade	N	Mean	SD	Post-hoc Comparison
1st Grade	196	4.20	0.806	Not significantly different from 3rd Lower than 1st and 3rd Higher than 2nd
2nd Grade	176	3.96	0.976	
3rd Grade	128	4.28	0.783	
Overall	500	3.96	0.816	F = 5.88, p = 0.003

Further analysis by school region, detailed in Table 5, revealed that students in the Central region reported significantly higher overall teacher leadership scores (M = 4.42, SD = 0.790) than those from the North (M = 4.00, SD = 0.654) or South/East (M = 3.96, SD = 0.943) regions. These significant regional differences may reflect variations in teaching practices, resource allocation, or institutional culture across different regions. The robust statistical differences highlight the importance of contextual factors in shaping students’ perceptions of leadership in practice-oriented settings.

Table 5. ANOVA results for teacher leadership by school region.

Region	N	Mean	SD	Post-hoc Comparison
North	153	4.00	0.654	Lower than Central Higher than North and South/East —
Central	170	4.42	0.790	
South/East	177	3.96	0.943	
Overall	500	3.96	0.816	F = 17.69, p < 0.001

3.5. Group Comparisons for Student Learning Effectiveness

Group comparisons for student learning effectiveness were conducted using independent sample t-tests and one-way ANOVA to determine whether demographic variables influenced the overall learning outcomes. The t-test results for gender showed no significant differences in overall learning effectiveness between male and female students (t = -0.592, p = 0.554), indicating a consistent perception of the curriculum’s effectiveness across genders. In contrast, comparisons across grade levels revealed statistically significant differences. As presented in Table 6, third-year students (M = 4.26, SD = 0.705) reported higher overall learning effectiveness than second-year students (M = 3.96, SD = 0.829). These findings suggest that as students advance through the program, their appreciation for the integration of theoretical knowledge with practical application increases.

Table 6. ANOVA results for student learning effectiveness by grade level.

Grade	N	Mean	SD	Post-hoc Comparison
1st Grade	196	4.12	0.725	— Lower than 3rd Higher than 2nd
2nd Grade	176	3.96	0.829	
3rd Grade	128	4.26	0.705	
Overall	500	4.10	0.766	F = 5.94, p = 0.003

When analyzed by school region, the results (see Table 7) indicate that students in the Central region had a significantly higher overall learning effectiveness score (M = 4.32, SD = 0.783) compared to those in the North (M = 4.00, SD = 0.654) and South/East (M = 3.99, SD = 0.800). These regional differences mirror the findings observed in the teacher leadership comparisons, suggesting that regional context may exert a simultaneous influence on both instructional practices and learning outcomes.

Table 7. ANOVA results for student learning effectiveness by school region.

Region	N	Mean	SD	Post-hoc Comparison
North	153	4.00	0.654	Lower than Central Higher than North and South/East —
Central	170	4.32	0.783	
South/East	177	3.99	0.800	
Overall	500	4.10	0.766	F = 10.42, p < 0.001

3.6. Correlation Analysis

Pearson’s product-moment correlation analysis was conducted to explore the strength and direction of the association between teacher leadership and student learning effectiveness. The overall correlation coefficient was 0.85 ($p < 0.001$), indicating a very strong positive relationship between effective teacher leadership and higher levels of student learning outcomes. Furthermore, analysis of individual dimensions revealed that specific aspects of teacher leadership—such as Charismatic Influence and Motivational Encouragement—were strongly correlated with key dimensions of learning effectiveness like Professional Cognition and Learning Activities. These robust correlations suggest that improvements in teacher leadership practices are likely to yield corresponding enhancements in student learning outcomes, thereby supporting the central hypothesis of the study. Table 8 provides a concise summary of the major correlation coefficients observed.

Table 8. Pearson correlation coefficients between teacher leadership and student learning effectiveness.

Variables	Correlation (r)	p-value
Overall Teacher Leadership & Overall Learning Effectiveness	0.85	<0.001
Charismatic Influence & Professional Cognition	0.78	<0.001
Motivational Encouragement & Learning Activities	0.76	<0.001
Intellectual Stimulation & Group Interaction	0.74	<0.001

The strong correlation between the leadership and learning scales emphasizes the interconnected nature of effective educational practices in vocational settings. The high correlation values indicate that teacher leadership is a critical driver of student learning, reinforcing the idea that fostering a supportive, engaging, and well-structured classroom environment is integral to achieving higher academic and professional outcomes in the field of fowl and livestock health care.

4. Discussion

4.1. Summary of Key Findings

The findings of this study provide strong evidence supporting the significant role of teacher leadership in enhancing student learning outcomes in practice-oriented curricula within the Department of Fowl and Livestock Health Care at vocational high schools. The data indicated that effective teacher leadership, particularly in dimensions such as Charismatic Influence and Motivational Encouragement, positively impacted students’ learning effectiveness. These findings are consistent with previous literature that emphasizes the importance of leadership in shaping classroom dynamics and improving academic engagement. Furthermore, significant differences in leadership perceptions and learning effectiveness were observed across different grade levels, with third-year students reporting higher levels of both teacher leadership and learning effectiveness. This suggests that as students progress through their education, their appreciation for and engagement with effective leadership practices grows, potentially due to increased exposure to complex, practice-oriented content. Additionally, regional differences, particularly higher scores in the Central region, highlight the importance of contextual factors such as institutional resources and regional teaching practices in shaping educational outcomes.

In addition to validating the theoretical model of teacher leadership, these results emphasize the multifaceted nature of effective teaching, which goes beyond knowledge delivery and extends into motivational and relational aspects of leadership. By exploring both the perceptions of leadership and measurable learning outcomes, the study provides a more comprehensive understanding of how teachers' leadership behaviors influence vocational education. This underlines the importance of fostering leadership skills in teachers to not only improve academic outcomes but also to align educational practices with the broader goals of sustainable agricultural development.

4.2. Implications for Teacher Leadership

The study's findings underscore the central role of teacher leadership in creating an environment that enhances student learning effectiveness. The strong correlations between teacher leadership dimensions such as Charismatic Influence and Motivational Encouragement, and student engagement, suggest that teachers who inspire and motivate students not only improve academic performance but also cultivate a positive classroom atmosphere conducive to learning. This highlights the importance of developing leadership skills in vocational education teachers to improve not just the technical proficiency of students but also their soft skills, such as critical thinking, communication, and teamwork.

Given these results, educational leaders and policymakers should consider incorporating leadership training as a core component of professional development for teachers. Programs that emphasize the development of charismatic and motivational leadership styles could have a significant impact on student learning. Furthermore, fostering individualized care and providing contingent rewards are strategies that could be particularly beneficial in practice-oriented settings where students often struggle to link theoretical knowledge with real-world applications. These findings suggest that effective teacher leadership is not a static quality but a dynamic set of behaviors that can be cultivated and refined to meet the needs of diverse student populations. As such, enhancing teacher leadership should be seen as a key lever for improving educational quality and addressing the evolving demands of vocational education.

4.3. Implications for Student Learning Effectiveness

Student learning effectiveness, as measured in this study, was positively influenced by teacher leadership, particularly in the dimensions of professional cognition, learning activities, and group interaction. Students in higher grades and those in the Central region, where teacher leadership was perceived most positively, reported significantly higher learning effectiveness. This suggests that teacher leadership plays a critical role not only in improving academic performance but also in fostering collaborative and interactive learning environments, which are essential in vocational education settings.

The high mean score for professional cognition indicates that students believe their curriculum is effectively preparing them for the technical challenges of the industry. This is particularly relevant for vocational education, where the integration of theory and practice is crucial for long-term professional success. Additionally, the moderate scores in learning activities and group interaction reflect that while students are engaged in active learning, there is room for further improvement in terms of enhancing student participation and collaboration. Teachers who excel in leadership are better equipped to foster these types of interactions, which are essential for preparing students for the teamwork-oriented environment they will encounter in their careers. These findings suggest that improving teacher leadership practices can significantly enhance the effectiveness of vocational curricula by promoting deeper learning and stronger collaboration among students.

4.4. Regional and Grade-Level Differences

This study also found significant differences in teacher leadership perceptions and student learning effectiveness across grade levels and regions. Third-year students reported higher levels of both teacher leadership and learning effectiveness compared to their peers in lower grades, suggesting that

exposure to a more advanced curriculum and greater instructional experience may enhance students' perceptions of their teachers' leadership. These results underscore the importance of the cumulative nature of vocational education, where students' understanding and appreciation of leadership grows as they progress through the program and engage with more complex content. Furthermore, the fact that regional differences were observed, with students in the Central region reporting the highest leadership perception and learning effectiveness scores, suggests that factors such as local educational practices, resource allocation, and perhaps regional socioeconomic conditions play a significant role in shaping educational outcomes.

These findings have important implications for policy and practice, particularly for schools in regions where lower leadership perceptions and learning effectiveness were reported. Targeted interventions, such as professional development programs focused on leadership practices and resource investment in underperforming regions, may be effective strategies for enhancing teacher leadership and improving student outcomes. The regional disparities highlighted in this study point to the need for a more nuanced understanding of how contextual factors influence education, and for the development of policies that address these differences.

4.5. Influence of Certification and Competition Experience

While certification status and competition experience did not emerge as statistically significant predictors of teacher leadership perception or student learning effectiveness in this study, these factors are still important considerations for future research. The relatively small number of students with certifications or competition experience may have limited the ability to detect potential effects. However, it is plausible that these variables play an indirect role in shaping students' engagement and motivation. Certification and competition experience are often markers of a student's commitment to their field and their ability to apply knowledge in real-world settings. It would be valuable to further investigate how these factors influence students' perceptions of teacher leadership and learning effectiveness, especially in larger and more diverse samples where these variables may be more pronounced.

Future studies could examine the potential interaction between extracurricular experiences (such as competition participation) and teacher leadership in fostering deeper learning. Additionally, exploring the types of certifications that students hold could provide insights into the specific competencies students are developing and how these may align with the skills needed in the agricultural sector. By understanding these relationships more fully, educators could tailor their teaching strategies to better support students' academic and professional growth.

4.6. Sustainability Integration in Vocational Education

A significant aspect of this study is its alignment with sustainable development goals, particularly SDG 4 (Quality Education) and SDG 2 (Zero Hunger). The findings suggest that teacher leadership, when effectively implemented, not only enhances student learning outcomes but also contributes to the broader objectives of sustainable development. Vocational education, particularly in fields like fowl and livestock health care, plays a pivotal role in preparing students to meet the challenges of sustainable agricultural practices. As such, integrating sustainability-focused content into the curriculum is crucial for preparing the next generation of professionals to address global challenges related to food security and environmental management.

The strong connection between teacher leadership and learning effectiveness found in this study further emphasizes the need for educators to foster a learning environment that is both academically rigorous and oriented towards sustainable practices. Teachers who adopt sustainable pedagogical approaches—such as promoting environmental responsibility and integrating sustainable agriculture techniques into their teaching—can help students develop the knowledge and skills necessary for implementing sustainable solutions in the agricultural sector. This highlights the importance of aligning vocational curricula with the overarching goals of sustainability, ensuring that students are

not only technically proficient but also environmentally conscious professionals ready to lead in the future of agriculture.

4.7. Limitations and Future Research Directions

While this study provides valuable insights into the relationship between teacher leadership and student learning effectiveness, several limitations should be considered. First, the study relied on self-reported data, which may introduce response biases, despite efforts to ensure anonymity and confidentiality. Future research should explore the use of objective performance measures to complement self-reported data and provide a more comprehensive understanding of the impact of teacher leadership. Second, the cross-sectional design of the study limits the ability to make causal inferences. Longitudinal studies would be particularly valuable in examining how teacher leadership influences student outcomes over time, especially as students progress through the vocational curriculum.

Furthermore, this study focused on a specific vocational discipline—fowl and livestock health care—at vocational high schools in Taiwan. Future research could expand the scope to include other vocational fields and regions, both within Taiwan and internationally, to explore how the findings generalize to other contexts. Additionally, further investigations should consider incorporating qualitative research methods, such as interviews or case studies, to gain deeper insights into how teacher leadership practices are enacted in the classroom and how they influence student behavior and learning outcomes. By addressing these limitations and exploring new areas of inquiry, future research can continue to refine our understanding of the complex relationships between teacher leadership and student learning effectiveness in vocational education.

5. Conclusion

5.1. Summary of Findings

The findings of this study emphasize the significant role of teacher leadership in enhancing student learning effectiveness within the practice-oriented professional curricula of the Department of Fowl and Livestock Health Care at vocational high schools in Taiwan. The study revealed that teacher leadership, especially in the dimensions of Charismatic Influence and Motivational Encouragement, positively impacts students' engagement, cognitive development, and overall learning outcomes. In particular, third-year students and those in the Central region reported higher levels of both leadership perception and learning effectiveness, suggesting that prolonged exposure to both the curriculum and experienced leadership practices can foster deeper student engagement. The strong positive correlations between teacher leadership and student learning effectiveness further corroborate the critical role of effective leadership in vocational education.

These results contribute to the growing body of research on teacher leadership in vocational settings, providing empirical evidence that not only validates the theoretical model but also underscores the need for more targeted and nuanced leadership strategies in vocational education. By highlighting the importance of specific leadership dimensions, such as charismatic influence and motivational encouragement, this study offers actionable insights into the practical applications of teacher leadership. Furthermore, the study confirms the complex relationship between instructional leadership and learning outcomes, suggesting that improvements in leadership practices can significantly enhance the effectiveness of vocational education.

5.2. Implications for Policy and Practice

The study's findings have several important implications for policy and practice, particularly in the context of vocational education. First, the positive relationship between teacher leadership and student learning effectiveness underscores the need for professional development programs focused on enhancing teacher leadership competencies. As demonstrated in this study, leadership styles such as Charismatic Influence and Motivational Encouragement have a significant impact on students' academic and professional outcomes. Therefore, educational institutions and policymakers should

prioritize leadership training as a critical component of teacher development, helping educators refine their skills in fostering student engagement, motivation, and active participation.

Additionally, the regional differences in teacher leadership and learning effectiveness observed in this study suggest that there is a need for region-specific interventions. Schools in regions with lower leadership perceptions may benefit from targeted professional development programs aimed at improving teachers' leadership capabilities. Furthermore, the results indicate that grade-level differences in perceptions of teacher leadership may reflect the cumulative effect of exposure to leadership practices over time. This highlights the need for a longitudinal approach to leadership development, ensuring that leadership practices evolve in tandem with students' increasing academic and professional demands. By tailoring leadership interventions to the specific needs of students and regions, policymakers can more effectively address disparities and promote equitable learning outcomes across diverse educational settings.

5.3. Limitations of the Study

While this study offers valuable insights into the relationship between teacher leadership and student learning effectiveness, it is not without its limitations. First, the study relied on self-reported data, which is inherently subjective and may be influenced by response biases such as social desirability. Despite efforts to ensure participant anonymity and confidentiality, self-reported measures may not always reflect an objective view of the students' experiences. To mitigate this limitation, future research could incorporate multiple sources of data, such as objective academic performance measures or teacher assessments, to provide a more comprehensive understanding of the impact of teacher leadership.

Second, the study utilized a cross-sectional design, which restricts the ability to infer causal relationships between teacher leadership and student outcomes. While the study clearly demonstrates a strong association between the two, longitudinal research would be more effective in determining whether changes in teacher leadership practices over time directly lead to improvements in student learning effectiveness. Additionally, the sample for this study was limited to the Department of Fowl and Livestock Health Care within vocational high schools in Taiwan. While the findings are relevant to the study population, they may not necessarily be generalizable to other vocational disciplines or educational contexts. Expanding the scope of future studies to include a wider range of vocational programs and regions would provide a more comprehensive understanding of the dynamics at play.

5.4. Future Research Directions

Building on the findings of this study, future research should explore several avenues to further understand the relationship between teacher leadership and student learning effectiveness. One important direction is to investigate the long-term effects of teacher leadership on student learning outcomes. A longitudinal design would allow for a deeper examination of how sustained exposure to effective leadership practices influences students over the course of their vocational training and beyond. Additionally, future studies could explore the impact of specific leadership behaviors on particular aspects of student development, such as problem-solving skills, technical proficiency, and professional attitudes, to provide a more detailed understanding of how leadership practices shape vocational education outcomes.

Further research should also consider examining the role of contextual factors in shaping teacher leadership and student learning outcomes. For instance, exploring how institutional resources, regional policies, and cultural differences influence the implementation and effectiveness of teacher leadership in vocational settings would provide valuable insights for policymakers and educational leaders. Additionally, a mixed-methods approach combining quantitative surveys with qualitative interviews or case studies would allow for a more nuanced understanding of the mechanisms through which teacher leadership impacts student learning. By delving deeper into the lived experiences of students and teachers, future studies could uncover the specific challenges and strategies that influence the effectiveness of teacher leadership in diverse educational environments.

Another key area for future research is the integration of sustainability principles into vocational curricula. This study has shown that teacher leadership plays a significant role in promoting student learning, and integrating sustainability-focused teaching practices could further enhance both student engagement and long-term professional development. Research that investigates the specific ways in which sustainability concepts can be embedded into vocational education programs will be crucial in preparing students for the challenges of sustainable agricultural practices. Such studies would not only help bridge the gap between theory and practice but also contribute to the broader goals of sustainability in education and the agricultural sector.

5.5. Concluding Remarks

In conclusion, this study contributes to the growing body of research on teacher leadership in vocational education, particularly in the context of sustainable agricultural practices. By establishing the significant relationship between teacher leadership and student learning effectiveness, it highlights the importance of investing in teacher development and leadership training programs to improve educational outcomes. The findings suggest that teacher leadership, when effectively implemented, can enhance both the academic performance and professional readiness of students, thereby contributing to the broader goals of sustainable development. While there are several limitations to the study, the insights gained provide a foundation for future research and practical interventions aimed at improving vocational education. Moving forward, it is essential that educational leaders and policymakers continue to refine teacher leadership strategies, ensuring that they align with the evolving needs of students and the demands of the agricultural sector, ultimately promoting a more sustainable and effective workforce.

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Abbreviations

The following abbreviations are used in this manuscript:

BEV	Battery Electric Vehicle
K-S	Kolmogorov-Smirnov one sample test
K-W	Kruskal-Wallis one-way analysis of variance by ranks
CSR	Corporate Social Reponsability
CRM	customer relationship management
SD	Standard Deviation
SDGs	Sustainable Development Goals

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