

ARTICLE

AI-Based and QR Code-Based Digital Attendance Systems as Predictors of Elementary School Teachers' Work Discipline in Rural Indonesia

Eka Prestianingsih,^{*,1} Achmad Buchori,¹ Fakhruddin,¹ and Mohamad Ikram bin Zakaria²

¹Magister Manajemen Pendidikan PGRI University of Semarang, Indonesia

²Fakulty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Malaysia

*Corresponding author: ekaprestianingsih123@gmail.com

(Received: 16 June 2026; Accepted: 09 Sept 2026; Published: 21 Sept 2026)

Abstract

This study aims to examine whether Artificial Intelligence (AI)-based digital attendance and QR Code-based digital attendance systems predict elementary school teachers' self-reported work discipline in Kedu District, Temanggung Regency, Indonesia. A quantitative approach was employed using a cross-sectional explanatory survey design with an ex post facto method. The population consisted of 192 teachers from 26 public elementary schools. Using the Slovin formula with a 5% margin of error, 130 teachers were selected through proportional random sampling. Data were collected during the 2025/2026 academic year using a structured questionnaire measured on a five-point Likert scale. The instruments demonstrated high reliability, with Cronbach's Alpha values ranging from 0.947 to 0.964. Data were analyzed using descriptive statistics and multiple linear regression analysis with IBM SPSS Statistics version 26. The findings indicate that AI-based digital attendance significantly predicts teachers' self-reported work discipline ($\beta = 0.216$, $p < .001$). QR Code-based digital attendance also significantly predicts self-reported work discipline and shows a stronger predictive contribution ($\beta = 0.599$, $p < .001$). The regression model demonstrates that both digital attendance systems collectively explain 48.3% of the variance in teachers' self-reported work discipline ($R^2 = 0.483$). These findings indicate that digital attendance systems are relevant administrative technologies associated with teacher discipline perceptions in rural elementary schools. However, because work discipline was measured through self-reported perceptions, the findings should be interpreted as predictive relationships rather than objective evidence of behavioral change. This study contributes to digital educational management research by integrating AI-based and QR Code-based attendance systems into a single predictive model and providing insights into technology-based administrative practices in rural school contexts.

Keywords: Artificial Intelligence; Digital Attendance; Digital Educational Management; QR Code; Teacher Work Discipline.

1. Introduction

Education plays a fundamental role in developing human resources capable of adapting to rapid technological, social, and economic transformations. However, enhancing educational quality requires more than effective teaching and learning processes; it also depends on robust administrative management practices that foster professional conduct and organizational effectiveness within educational institutions. In Indonesia, educational institutions continue to encounter persistent challenges, including regional disparities in educational quality, resource constraints, and weaknesses in educational administration and management systems [1], [2], [3]. These challenges underscore the need to strengthen school management mechanisms that promote teacher professionalism, improve organizational effectiveness, and ultimately contribute to the sustainable enhancement of educational quality.

Teachers constitute a central component of educational organizations, as their responsibilities extend beyond instructional activities to encompass professional commitment, administrative compliance, and adherence to institutional regulations. Within the broader domain of teacher professionalism, work discipline represents an important organizational behavior outcome because it reflects teachers' consistent commitment to fulfilling their professional responsibilities [4]. Teacher work discipline can be understood as the extent to which teachers comply with established professional standards and organizational expectations, including punctuality, preparation for instructional activities, completion of administrative duties, and adherence to institutional regulations. Unlike teacher performance, which generally emphasizes broader outcomes associated with instructional effectiveness and the achievement of educational objectives, work discipline focuses more specifically on behavioral consistency, responsibility, and compliance within the workplace. Although attendance is an important component of work discipline, it represents only one aspect of a broader construct that encompasses punctuality, professional responsibility, and compliance with organizational norms and regulations. Teachers who demonstrate high levels of work discipline are more likely to support effective learning environments, foster positive school cultures, and contribute to improved student outcomes [5], [6], [7].

From an educational management perspective, teacher work discipline is influenced by multiple organizational factors, including leadership, supervision mechanisms, organizational culture, incentives, sanctions, and professional commitment. Previous studies have demonstrated that academic supervision and school culture influence teacher performance and professional behavior [7]. In addition, the integration of technology into human resource management and educational administration has created new opportunities to enhance monitoring, accountability, and organizational discipline [8], [9]. Digital attendance systems represent one form of administrative innovation because they provide more systematic, transparent, and verifiable mechanisms for recording attendance-related information. Nevertheless, challenges related to teacher discipline, such as inconsistent punctuality, compliance with administrative responsibilities, and fulfillment of professional obligations, remain important concerns in educational organizations [10], [11]. Therefore, examining digital attendance systems as predictors of teacher work discipline provides an important perspective within educational management research.

The development of digital technology has transformed educational administration by enabling data-driven, transparent, and efficient management practices [12]. Digital transformation in education extends beyond instructional technology and includes administrative management, monitoring systems, and organizational decision-making processes [3]. Previous studies have shown that digitalization can improve governance through information systems, analytics, and technology-based monitoring mechanisms [13], [14]. One significant technological advancement within this transformation is Artificial Intelligence (AI), which enables systems to identify patterns, analyze information,

support predictions, and facilitate automated decision-making [13]. In educational administration, AI can support real-time monitoring, improve data accuracy, and enhance institutional efficiency [14], [15].

In this study, AI-based digital attendance is conceptualized as an attendance management system that incorporates intelligent computational capabilities beyond those provided by conventional digital attendance mechanisms. Whereas traditional digital attendance systems primarily record attendance through user identification and verification processes, AI-based systems incorporate intelligent verification, automated data processing, analytical capabilities, and/or AI-assisted decision support to enhance the accuracy and efficiency of attendance monitoring. Depending on their design and implementation context, such systems may integrate technologies including biometric authentication, geolocation, cloud computing, and facial recognition to strengthen attendance security, reliability, and real-time monitoring. Previous studies have demonstrated that AI-supported attendance systems can enhance monitoring accuracy, administrative efficiency, and data quality [16], [17]. Nevertheless, the effectiveness of AI-based attendance systems is not determined solely by their technological capabilities; successful implementation also depends on users' digital competence, technological readiness, and acceptance of technological change [18], [19], [20]. This suggests that the organizational value of AI-based attendance systems depends on the interaction between technological functionality and users' capacity and willingness to adopt and utilize the technology effectively.

Besides AI-based attendance, QR Code-based attendance represents another form of digital attendance technology with different characteristics. QR Code-based attendance relies on rapid digital identification through QR scanning mechanisms, emphasizing accessibility, simplicity, and operational efficiency. While AI-based attendance focuses on intelligent verification and analytical processing, QR Code-based attendance focuses on ease of operation, rapid recording, and direct user interaction. Therefore, these two technologies should be considered as distinct technological constructs within the broader domain of digital attendance systems rather than interchangeable forms of the same technology. Previous studies have demonstrated that QR Code-based attendance systems can reduce recording errors, accelerate attendance processing, and improve transparency in attendance management [21], [22], [23], [24], [25]. However, similar to AI-based systems, successful implementation of QR Code attendance depends on users' perceptions regarding usefulness and ease of use.

The relationship between digital attendance systems and teacher work discipline can be explained through the Technology Acceptance Model (TAM), which serves as the primary theoretical foundation of this study. TAM proposes that technology adoption is determined primarily by perceived usefulness and perceived ease of use. Users are more likely to accept and consistently utilize a technology when they perceive that the system provides benefits and requires limited effort. In the context of digital attendance systems, technological characteristics such as AI-based verification capability, QR Code accessibility, recording speed, accuracy, and administrative efficiency may influence teachers' perceptions of usefulness and ease of use. These perceptions may subsequently influence technology acceptance and compliance behavior, which are associated with teachers' self-reported work discipline.

Based on TAM, this study conceptualizes AI-based and QR Code-based digital attendance systems as technological predictors that may contribute to variations in teachers' self-reported work discipline through acceptance and compliance mechanisms. The proposed relationship follows the pathway: technology characteristics → perceived usefulness/perceived ease of use → technology acceptance and compliance behavior → self-reported work discipline.

However, technology acceptance alone may not fully explain how digital attendance systems are

related to workplace behavior. Therefore, Institutional Theory and Behavioral Control Theory are incorporated as complementary perspectives. Institutional Theory explains that organizational behavior is shaped by formal rules, norms, expectations, and accountability mechanisms. Within schools, digital attendance systems may strengthen institutional expectations by creating standardized, transparent, and verifiable attendance records [9]. Meanwhile, Behavioral Control Theory explains that monitoring mechanisms and behavioral regulation can influence individual compliance. Digital attendance systems may support behavioral control by increasing monitoring visibility, reducing opportunities for inaccurate attendance reporting, and reinforcing responsibility through documented records.

Although previous studies have investigated artificial intelligence, digital transformation, and QR Code-based attendance systems, much of the existing literature has concentrated on system development, technical performance, implementation, and administrative efficiency rather than on their potential influence on teachers' behavioral outcomes. Empirical evidence concerning the predictive relationship between AI-based and QR Code-based attendance systems and teachers' self-reported work discipline remains limited, particularly in rural elementary school settings. This gap is partly attributable to the tendency of previous research to examine these attendance technologies independently rather than comparatively within a common organizational and behavioral framework [3], [16], [23]. Moreover, research on teacher work discipline has frequently emphasized attendance-related behavior or overall teacher performance, with comparatively less attention to broader dimensions of professional responsibility, administrative compliance, and workplace behavioral consistency. Consequently, the relationship between technology-enabled attendance monitoring and teachers' broader work discipline remains insufficiently understood, particularly in resource-constrained rural educational contexts.

This study addresses these gaps by developing a predictive model that examines the relationship between AI-based and QR Code-based digital attendance systems and elementary school teachers' self-reported work discipline. The study focuses on public elementary schools in Kedu District, Temanggung Regency, Indonesia, representing a rural educational context where digital transformation provides both opportunities and implementation challenges.

Based on the proposed conceptual framework, this study examines whether AI-based and QR Code-based digital attendance systems significantly predict elementary school teachers' self-reported work discipline. Therefore, the hypotheses are formulated as follows: H1: AI-based digital attendance significantly predicts elementary school teachers' self-reported work discipline. H2: QR Code-based digital attendance significantly predicts elementary school teachers' self-reported work discipline. H3: AI-based and QR Code-based digital attendance systems collectively provide significant predictive value for elementary school teachers' self-reported work discipline.

2. Methods

This study employed a quantitative approach using a cross-sectional explanatory survey design with an ex post facto method to examine whether AI-based digital attendance and QR Code-based digital attendance systems predict elementary school teachers' self-reported work discipline. An explanatory survey design was used to analyze statistical relationships among variables based on respondents' perceptions, while the ex post facto approach was selected because the digital attendance systems had already been implemented without experimental manipulation. Therefore, the findings represent predictive relationships rather than causal effects. The research was conducted in public elementary schools located in Kedu District, Temanggung Regency, Central Java, Indonesia. Kedu District was selected because it represents a rural educational context where schools have adopted digital transformation initiatives while still facing challenges related to technological adaptation,

infrastructure readiness, and teacher digital competence. This setting provides an appropriate context for examining the relationship between digital attendance technologies and teacher behavioral outcomes in non-urban schools.

The population consisted of 192 elementary school teachers from 26 public elementary schools in Kedu District, Temanggung Regency. The sampling frame was based on the official list of active teachers registered during the 2025/2026 academic year. Schools were selected based on the following criteria: (1) public elementary schools located in Kedu District; (2) schools that had implemented AI-based and/or QR Code-based digital attendance systems; and (3) schools that allowed teacher participation. Teachers were selected as the unit of analysis because the dependent variable was teacher self-reported work discipline, referring to teachers' perceived compliance with professional responsibilities, organizational regulations, and workplace expectations.

The sample size was determined using the Slovin formula with a 5% margin of error, resulting in 130 respondents. Respondents were selected using proportional random sampling to ensure proportional representation from each participating school. The inclusion criteria were: (1) active elementary school teachers in Kedu District; (2) teachers who had experience using digital attendance systems implemented by their schools; (3) teachers who were able to evaluate the attendance system; (4) teachers who voluntarily participated; and (5) teachers who completed the questionnaire. Incomplete responses were excluded. The final sample consisted of 130 teachers, representing a response rate of 67.7% (130/192).

The study examined three variables: AI-based digital attendance (X_1), QR Code-based digital attendance (X_2), and teacher self-reported work discipline (Y). The operationalization of variables was developed based on previous theoretical concepts and empirical studies related to digital attendance systems, technology acceptance, organizational monitoring, and teacher professional behavior.

AI-based digital attendance refers to teachers' perceptions regarding the implementation and usefulness of artificial intelligence capabilities integrated into attendance systems. Unlike conventional digital or biometric attendance systems, AI-based attendance emphasizes intelligent verification, automated processing, analytical capability, and AI-assisted monitoring functions. The indicators were developed based on previous studies regarding AI-supported attendance systems [16], [13].

QR Code-based digital attendance refers to teachers' perceptions regarding the implementation and usability of QR Code technology for attendance recording and monitoring. This construct emphasizes accessibility, ease of scanning, operational simplicity, and rapid attendance recording. The indicators were developed based on previous studies regarding QR Code attendance systems [21], [25].

Teacher self-reported work discipline refers to teachers' perceptions regarding their own compliance with school regulations, professional responsibilities, punctuality, and workplace behavior. The construct was developed from concepts of professional responsibility, organizational discipline, punctuality, and professional conduct [5], [7]. Because standardized behavioral records were unavailable across all participating schools, the measurement reflects perceived discipline behavior rather than objectively observed disciplinary outcomes.

All variables were measured using a structured questionnaire with a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Higher scores indicate stronger perceptions of digital attendance system characteristics and higher levels of self-reported work discipline. Table 1 presents the operationalization of the research variables, including dimensions, indicators, number of items, measurement scale, scoring structure, and example questionnaire statements.

Table 1. Operationalization of Research Variables

Variable	Dimension	Indicators	Number of Items	Example Item
AI-Based Digital Attendance (X_1)	Intelligent verification and automation	AI-assisted verification, automated attendance processing	5 items	"The AI-based attendance system accurately verifies my attendance."
	Accuracy and monitoring capability	Accurate records, real-time monitoring	5 items	"The system provides reliable attendance records that can be monitored in real time."
	Administrative efficiency	Faster administrative processing and reduced errors	4 items	"The AI attendance system improves efficiency in attendance administration."
QR Code-Based Digital Attendance (X_2)	Ease of use and accessibility	Ease of scanning, accessibility, user friendliness	5 items	"The QR Code attendance system is easy for me to operate."
	Speed and accuracy	Fast recording and accurate attendance data	4 items	"QR Code attendance records my attendance quickly and accurately."
	Administrative efficiency	Improved attendance management process	4 items	"The QR Code system simplifies attendance administration."
Teacher Work Discipline (Y)	Attendance and punctuality	Attendance consistency and punctuality	5 items	"I attend school according to the established working schedule."
	Responsibility and compliance	Completion of duties and adherence to regulations	5 items	"I complete my professional responsibilities according to school regulations."
	Professional behavior and self-control	Professional conduct, co-operation, and communication	5 items	"I maintain professional behavior in carrying out my duties."

Teacher self-reported work discipline was measured through perceptions rather than direct behavioral observations. To minimize potential common method bias, questionnaire items were developed based on established theoretical dimensions and previous empirical studies [5], [7], [16], [25]. Respondents were informed that their responses were confidential and used only for academic purposes. Validity and reliability testing were conducted before hypothesis testing. However, self-reported measurement remains a limitation because perceptions may not fully represent objectively observed behavior. Future studies should integrate objective indicators, including digital attendance logs, lateness records, absenteeism data, and supervisor assessments.

Data analysis involved descriptive statistics and inferential analysis. Classical assumption tests were conducted before multiple linear regression analysis. Regression analysis was applied to examine whether AI-based digital attendance (X_1) and QR Code-based digital attendance (X_2) significantly predict teacher self-reported work discipline (Y). The regression model was formulated as

$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$. The t-test was used to examine individual predictors, the F-test was used to evaluate the overall model, and R^2 was used to determine the proportion of variance explained by both predictors. Statistical significance was determined at $\alpha = 0.05$.

3. Results and Discussion

3.1 Results

Before conducting statistical analysis, the reliability of the research instruments was examined using Cronbach's Alpha coefficient. Reliability testing was conducted to determine the internal consistency of the measurement items representing AI-based digital attendance (X_1), QR Code-based digital attendance (X_2), and teacher self-reported work discipline (Y). The reliability test results are presented in Table 2.

Table 2. Reliability Test Results of Research Instruments

Variable	Cronbach's Alpha	Interpretation
AI-Based Digital Attendance (X_1)	0.947	Excellent reliability
QR Code-Based Digital Attendance (X_2)	0.958	Excellent reliability
Teacher Work Discipline (Y)	0.964	Excellent reliability

Source: Processed research data (2026).

The results indicate that all variables obtained Cronbach's Alpha values above the recommended threshold of 0.70, demonstrating excellent internal consistency. Therefore, all measurement instruments were considered reliable and appropriate for further statistical analysis.

Descriptive Statistics of the Research Variables Descriptive statistical analysis was conducted to examine the characteristics of the three research variables: AI-based digital attendance (X_1), QR Code-based digital attendance (X_2), and teacher self-reported work discipline (Y). The analysis included mean, median, standard deviation, minimum, maximum, range, and 95% confidence interval (CI) of the mean. Table 3 presents the descriptive statistical results.

Table 3. Descriptive Statistics of the Research Variables

Variables	Mean	Median	Std. Deviation	Minimum	Maximum	Range	95% CI For Mean
Teacher Work Discipline (Y)	172.07	173.00	11.91	118.00	207.00	89.00	170.00 – 174.14
AI Based Digital Attendance (X_1)	173.89	173.00	11.61	147.00	210.00	63.00	171.88 – 175.91
QR Code Based Digital Attendance (X_2)	171.95	171.00	12.41	135.00	206.00	71.00	169.79 – 174.10

Source: Processed research data (2026).

The descriptive results indicate that respondents generally reported positive perceptions toward AI-based digital attendance, QR Code-based digital attendance, and their own work discipline. The relatively high mean scores suggest that digital attendance systems were implemented and perceived positively within the participating elementary schools.

Pearson Correlation Analysis A Pearson correlation analysis was conducted to examine the relationships among research variables and to provide preliminary evidence regarding the relationships

between the independent variables. The correlation coefficients among the variables are presented in Table ??.

Table 4. Pearson Correlation Matrix among Research Variables

Variables	Teacher Work Discipline (Y)	AI-Based Digital Attendance (X ₁)	QR Code-Based Digital Attendance (X ₂)
Teacher Work Discipline (Y)	1.000	0.594	0.692
AI-Based Digital Attendance (X ₁)	0.594	1.000	0.797
QR Code-Based Digital Attendance (X ₂)	0.692	0.797	1.000

Note: $p < 0.01$ (two-tailed); $N = 130$.
Source: Processed research data (2026).

The correlation analysis demonstrates that AI-based digital attendance had a moderate positive relationship with teacher self-reported work discipline ($r = 0.594, p < .001$). QR Code-based digital attendance showed a stronger positive relationship with teacher self-reported work discipline ($r = 0.692, p < .001$). These findings indicate that teachers who reported more positive perceptions of digital attendance systems also tended to report higher levels of work discipline. The correlation between AI-based and QR Code-based digital attendance was relatively high ($r = 0.797, p < .001$). This strong relationship indicates that both technologies share several characteristics as digital attendance systems, particularly in supporting attendance monitoring, recording accuracy, transparency, and administrative efficiency. However, the high correlation does not indicate that the two constructs represent the same technological concept.

Conceptually, AI-based digital attendance and QR Code-based digital attendance represent different technological approaches within the broader domain of digital attendance systems. AI-based digital attendance emphasizes intelligent verification, automated processing, analytical capability, and AI-assisted monitoring functions. In contrast, QR Code-based digital attendance emphasizes accessibility, ease of scanning, operational simplicity, and rapid attendance recording. Therefore, the observed correlation reflects their shared role in improving digital attendance management while maintaining distinct technological characteristics and user interaction mechanisms.

To determine whether the high correlation affected the regression model, multicollinearity testing was conducted using the Variance Inflation Factor (VIF). The VIF value obtained was 2.746, which is below the commonly accepted threshold of 10. Therefore, although AI-based and QR Code-based digital attendance systems are strongly related conceptually and statistically, both variables remain distinguishable and suitable for inclusion as separate predictors in the regression model.

3.1.1 Classical Assumption Tests

Before conducting multiple linear regression analysis, normality, linearity, multicollinearity, and heteroscedasticity tests were performed. The results are summarized in Table 5.

Table 5. Classical Assumption Test Results

Type of Test	Indicator	Value	Criterion	Decision
Kolmogorov-Smirnov Test	Asymp. Sig.	0.200	> 0.05	Normal
Linearity X ₁ with Y	Sig. Deviation from Linearity	0.997	> 0.05	Linear

Continued on next page

Table 5 – Continued from previous page

Type of Test	Indicator	Value	Criterion	Decision
Linearity X_2 with Y	Sig. Deviation from Linearity	0.368	> 0.05	Linear
Multicollinearity	VIF	2.746	< 10	No Multicollinearity
Heteroscedasticity (X_1)	Sig.	0.397	> 0.05	No Heteroscedasticity
Heteroscedasticity (X_2)	Sig.	0.574	> 0.05	No Heteroscedasticity

Source: Processed research data (2026).

The Kolmogorov-Smirnov test produced an Asymp. Sig. value of 0.200, indicating that the regression residuals were normally distributed. The deviation-from-linearity values for $X_1 - Y$ (0.997) and $X_2 - Y$ (0.368) confirmed linear relationships. The VIF value of 2.746 indicated that multicollinearity was not a concern despite the relatively high correlation between X_1 and X_2 . The heteroscedasticity tests for X_1 (0.397) and X_2 (0.574) exceeded 0.05, indicating homoscedastic residual variance.

3.1.2 Multiple Linear Regression Analysis

Multiple linear regression analysis was conducted to examine whether AI-based and QR Code-based digital attendance systems significantly predict teacher self-reported work discipline. The regression results are presented in Table 6.

Table 6. Results of the Multiple Linear Regression Analysis

Variables	B	β	t	Sig.
Constant	52.535	–	4.510	< 0.001
AI Based Digital Attendance (X_1)	0.419	0.216	3.101	< 0.001
QR Code Based Digital Attendance (X_2)	0.575	0.599	5.667	< 0.001

Dependent variable: Teacher Work Discipline (Y)

Source: Processed research data (2026).

The regression equation was: $Y = 52.535 + 0.419X_1 + 0.575X_2 + \varepsilon$. The regression results indicate that AI-based digital attendance significantly predicts teacher self-reported work discipline ($\beta = 0.216$, $t = 3.101$, $p < .001$). Therefore, H1 was supported. QR Code-based digital attendance also significantly predicts teacher self-reported work discipline ($\beta = 0.599$, $t = 5.667$, $p < .001$), supporting H2. The standardized coefficient indicates that QR Code-based digital attendance provides a stronger predictive contribution compared with AI-based digital attendance.

3.2 Discussion

3.2.1 AI-Based Digital Attendance as a Predictor of Teacher Work Discipline

The findings of this study indicate that AI-based digital attendance significantly predicts elementary school teachers' self-reported work discipline. This finding suggests that teachers who perceive AI-based attendance systems more positively tend to report higher levels of discipline related to punctuality, attendance accountability, and professional responsibility. AI-based attendance systems may contribute to this relationship through automated verification, real-time monitoring, and improved attendance record accuracy, which can support transparency and reduce opportunities for inaccurate attendance reporting.

The observed relationship can be interpreted through the Technology Acceptance Model (TAM), which posits that technology acceptance is primarily shaped by users' perceptions of its usefulness

and ease of use. In the context of teacher attendance management, AI-based systems may provide functional advantages through intelligent verification, automated data processing, and data-driven monitoring. When teachers perceive such systems as useful for improving administrative efficiency, enhancing transparency, and strengthening institutional accountability, they may be more inclined to accept the technology and comply with established attendance procedures. This interpretation is further supported by Institutional Theory, which suggests that organizational practices and formal rules can shape individual behavior by establishing shared norms and expectations.

From this perspective, digital attendance systems may reinforce institutional norms by translating attendance regulations into transparent, standardized, and traceable records [9]. In addition, Behavioral Control Theory provides a complementary explanation by emphasizing the role of monitoring and perceived behavioral constraints in shaping compliance. Automated monitoring mechanisms may strengthen accountability by increasing the visibility and traceability of attendance behavior, while simultaneously reducing opportunities for inaccurate reporting or attendance manipulation. Taken together, these theoretical perspectives suggest that AI-based attendance systems may be associated with teacher work discipline through interconnected technological, institutional, and behavioral mechanisms.

The finding is consistent with previous studies demonstrating that artificial intelligence can support educational administration through improved data analysis, monitoring capability, and evidence-based decision-making [13], [14], [26], [27], [28], [29]. Previous research has also shown that AI-based attendance systems can improve attendance verification accuracy, administrative efficiency, and monitoring effectiveness [16], [17]. In addition, digital human resource management studies indicate that technology-supported monitoring systems can strengthen organizational accountability and support more objective management processes [30], [31], [32], [33]. However, this study provides a different perspective compared with previous studies that often emphasize the technological advantages of AI systems. Although AI-based attendance demonstrated a significant predictive relationship with teacher discipline, its contribution was weaker than QR Code-based attendance. This finding suggests that technological sophistication does not automatically translate into stronger behavioral outcomes. While AI provides advanced capabilities such as intelligent recognition, automated analysis, and predictive functions, many of these processes occur behind the system interface and may not be directly experienced by teachers in daily attendance activities.

This result extends previous research by indicating that the behavioral value of AI-based systems depends not only on technological capability but also on user experience, digital competence, training availability, and organizational readiness. Previous studies have emphasized that successful AI implementation requires digital competence, user readiness, and organizational support [19], [20], [34], [35], [36], [37]. Therefore, differences in implementation quality, technical assistance, system reliability, infrastructure availability, and teacher familiarity may explain variations in how AI-based attendance systems are associated with teacher discipline.

3.2.2 QR Code-Based Digital Attendance as a Predictor of Teacher Work Discipline

The findings demonstrate that QR Code-based digital attendance significantly predicts teacher self-reported work discipline and provides a stronger predictive contribution compared with AI-based attendance. This finding indicates that technological characteristics closely connected with teachers' daily activities, particularly simplicity, accessibility, speed, and direct interaction, may generate stronger behavioral responses.

This finding is consistent with TAM, which explains that perceived usefulness and perceived ease of use influence technology acceptance and utilization [38]. QR Code-based attendance provides a straightforward process through which teachers perform scanning activities and immediately receive attendance confirmation. This direct interaction may strengthen the relationship between

individual behavior and organizational expectations. From the perspective of Institutional Theory, QR Code attendance also strengthens organizational accountability by establishing standardized attendance procedures and transparent digital records [9]. Behavioral Control Theory further explains that immediate recording and monitoring mechanisms encourage compliance because teachers are aware that their attendance behavior is systematically documented.

The findings support previous studies showing that QR Code-based attendance systems improve attendance recording efficiency, transparency, accessibility, and administrative management [21], [22], [23], [24], [25]. Previous research has demonstrated that QR Code systems can accelerate attendance processes, reduce recording errors, and support effective monitoring mechanisms in educational and organizational environments [17], [18], [39], [40], [41], [42], [43], [44].

However, unlike previous studies that primarily highlight technical efficiency, this study contributes additional evidence regarding behavioral outcomes. The stronger predictive contribution of QR Code-based attendance compared with AI-based attendance suggests that usability and direct user engagement may be more influential than technological complexity in shaping teacher discipline. In rural educational contexts, where digital competence and technological resources may vary, systems requiring fewer operational demands may produce more consistent behavioral responses.

This finding does not indicate that QR Code technology is universally superior to AI technology. Instead, it suggests that the effectiveness of digital attendance systems depends on the alignment between technological characteristics, user capability, organizational readiness, and institutional needs. Previous studies have emphasized that successful digital transformation requires user participation, organizational readiness, and alignment between technology and institutional conditions [28], [45], [46], [38], [47], [48].

3.2.3 Predictive Contribution of AI-Based and QR Code-Based Digital Attendance Systems

The overall regression model demonstrates that AI-based and QR Code-based digital attendance systems significantly predict teacher self-reported work discipline ($F = 59.424$, $p < .001$), explaining 48.3% of the variance in teacher discipline. This finding indicates that digital attendance technologies collectively contribute to strengthening accountability, monitoring, and compliance mechanisms within schools.

This finding supports the integration of TAM, Institutional Theory, and Behavioral Control Theory. TAM explains that teachers are more likely to adopt digital attendance systems when they perceive them as useful and easy to use [38]. AI-based attendance contributes through intelligent verification, automated processing, and data analysis, whereas QR Code-based attendance contributes through accessibility, simplicity, and immediate confirmation. Institutional Theory explains that digital attendance strengthens organizational norms through standardized and verifiable records [9]. Meanwhile, Behavioral Control Theory explains that continuous monitoring mechanisms increase accountability and encourage compliance.

The finding is consistent with previous research demonstrating that digital technologies can improve organizational governance, transparency, monitoring effectiveness, and data-driven decision-making. Previous studies also indicate that artificial intelligence and digital transformation support administrative efficiency and evidence-based management practices [49], [50], [30], [31], [32].

Nevertheless, the model explains only 48.3% of the variance, indicating that 51.7% of teacher self-reported work discipline is explained by other factors outside the model. This unexplained variance provides an important direction for future research. Teacher discipline is a multidimensional organizational behavior that may also be influenced by leadership style, academic supervision, school organizational culture, professional commitment, motivation, workload, and institutional enforcement mechanisms [5], [6], [7]. In addition, individual digital competence, technology anxiety, train-

ing experience, and perceived organizational support may influence how teachers respond to digital attendance systems [19], [20].

Contextual factors may also contribute to the remaining variance. Differences in infrastructure quality, internet stability, technical support availability, and consistency of school policies may affect the extent to which digital attendance systems are integrated into daily professional practices. Therefore, digital attendance should not be viewed as an independent solution for improving teacher discipline but as one component within a broader educational management system.

This study contributes to digital educational management literature by extending understanding of digital attendance systems from technical implementation toward organizational behavior outcomes. While previous research has frequently examined attendance technologies separately or focused on system functionality, this study demonstrates that multiple digital attendance approaches can jointly predict teacher self-reported work discipline through mechanisms of technology acceptance, accountability, and behavioral control [35], [37], [51], [52]. These findings imply that schools should not only adopt digital technologies but also ensure adequate training, infrastructure support, leadership commitment, and implementation strategies to maximize their organizational value.

4. Conclusion

This study demonstrates that AI-based digital attendance and QR Code-based digital attendance systems are significant predictors of elementary school teachers' self-reported work discipline in Kedu District, Temanggung Regency. The findings indicate that teachers who reported more positive perceptions of AI-based digital attendance also tended to report higher levels of work discipline. Similarly, QR Code-based digital attendance demonstrated a stronger predictive contribution than AI-based digital attendance within the regression model. However, this difference should be interpreted based on the measured predictive relationships rather than assuming that QR Code-based attendance is inherently superior or that specific technological characteristics directly cause stronger discipline outcomes.

The simultaneous regression analysis further indicates that AI-based and QR Code-based digital attendance systems collectively explain a substantial proportion of the variance in teachers' self-reported work discipline. These findings suggest that digital attendance systems represent relevant administrative technologies within educational management contexts, particularly in supporting structured attendance monitoring practices. However, the findings should be interpreted within the scope of the variables examined, as this study measured teachers' perceptions of digital attendance systems and self-reported work discipline rather than objective behavioral changes.

From a practical perspective, school administrators should consider the alignment between digital attendance implementation and teachers' experiences when adopting attendance technologies. Schools implementing AI-based attendance systems should ensure adequate technical support, user guidance, and continuous evaluation to facilitate effective utilization. Similarly, schools implementing QR Code-based attendance systems should maintain consistent procedures, system reliability, and clear attendance regulations. Rather than focusing solely on technological sophistication, educational institutions should consider implementation readiness, teacher acceptance, and contextual suitability when managing digital transformation initiatives.

For policymakers and local education authorities, the findings highlight the importance of supporting digital transformation through comprehensive implementation strategies. Providing digital infrastructure, teacher technology development programs, technical assistance, and evaluation mechanisms may support sustainable adoption of digital attendance systems, particularly in rural educational settings. However, technology implementation should be accompanied by organizational

support factors because digital attendance represents only one component of teacher discipline management.

Several limitations should be acknowledged when interpreting the findings of this study. First, the study relied on self-reported questionnaire data, which may be subject to subjective perceptions, recall errors, and social desirability bias. The exclusive use of self-reported measures may also introduce common-method bias, particularly when both technology-related perceptions and teacher work discipline are assessed using the same data source. Second, the cross-sectional *ex post facto* design limits the ability to establish temporal precedence and, consequently, to draw causal inferences regarding the relationships between digital attendance systems and teacher work discipline. Third, the study was conducted among public elementary school teachers in Kedu District, Temanggung Regency, which may constrain the external validity of the findings and limit their transferability to other geographical regions, educational levels, school ownership structures, or institutional contexts. In addition, potential selection bias cannot be ruled out because the study included schools that had already implemented digital attendance systems. Teachers working in these schools may differ systematically from those in schools that have not adopted such systems in terms of technological readiness, organizational practices, leadership, or institutional resources.

Future research should address these limitations by employing longitudinal, quasi-experimental, or comparative research designs that provide stronger evidence regarding temporal relationships and potential causal mechanisms. Researchers should also integrate self-reported measures with objective behavioral indicators, including digital attendance logs, absenteeism records, punctuality data, administrative records, and supervisor assessments, to reduce reliance on a single data source and strengthen measurement validity. Further research could also incorporate additional explanatory variables that were not examined in the present model, such as digital leadership, organizational culture, teachers' digital competence, technology readiness, professional commitment, and implementation quality. Examining these factors may help clarify the organizational and individual mechanisms through which digital attendance systems are associated with teacher professional behavior. Extending such investigations across different geographical regions, educational levels, and institutional settings would further enhance the robustness and generalizability of the evidence concerning technology-enabled attendance management and teacher work discipline.

References

- [1] E. Ningrum. "Pengembangan Sumber Daya Manusia Bidang Pendidikan". In: *Jurnal Pendidikan Geografi* 9.1 (Mar. 2016). doi: 10.17509/gea.v9i1.1681.
- [2] N. N. Anissa' Oktavianatun. *Analisis Perkembangan Pendidikan Berkualitas Sebagai Upaya Mewujudkan Tujuan Pembangunan Berkelanjutan (SDGs)*. May 2024. doi: 10.5281/ZENODO.11181016.
- [3] U. Jayadi, A. Harahap, and A. Aslan. "Educational Landscape in Indonesia in 2023: Challenges and Opportunities". In: *International Journal of Education and Digital Learning (IJEDL)* 2.2 (Dec. 2024), pp. 49–58. doi: 10.47353/ijedl.v2i2.266.
- [4] T. P. Muslimin and A. A. B. Fatimah. "Kompetensi dan Kesiapan Guru Sekolah Dasar Terhadap Tantangan Pendidikan di Era Society 5.0". In: *CJPE* 7.1 (Apr. 2024), pp. 55–72. doi: 10.30605/cjpe.7.1.2024.3589.
- [5] B. Barnawi. *Kinerja Guru Profesional: Instrumen Pembinaan, Peningkatan dan Penilaian*. Yogyakarta: Ar Ruzz Media, 2020.
- [6] E. Sutrisno. *Manajemen Sumber Daya Manusia*. Jakarta: Prenadamedia Group, 2020.
- [7] M. U. Hasibuan. *Manajemen Sumber Daya Manusia*. Revisi. Jakarta: Bumi Aksara, 2022.

- [8] Z. Zulianto, A. Buchori, and B. A. Saputra. "Pengaruh Supervisi Akademik dan Budaya Sekolah Terhadap Kinerja Guru SD di Kecamatan Pecalongan Kabupaten Batang". In: *MPP* 17.2 (Dec. 2023), pp. 242–255. doi: 10.26877/mpp.v17i2.15178.
- [9] Andi Zainal Abidin, Muhammad Taraki, Lidin Wiwah Jaya Putra, Jamrizal Jamrizal, and Samsu Samsu. "Pengaruh Teknologi Membangun Budaya Organisasi: Penggunaan Fingerprint dan Aplikasi Presensi di Pondok Pesantren Darul Arifin Jambi". In: *Hikmah* 2.1 (Dec. 2024), pp. 47–53. doi: 10.61132/hikmah.v2i1.516.
- [10] N. K. W. Oktaviani and M. Putra. "Motivasi dan Disiplin Kerja Terhadap Kinerja Guru di Sekolah Dasar". In: *JIPP* 5.2 (July 2021), p. 294. doi: 10.23887/jipp.v5i2.35146.
- [11] I. Dekawati. "Kontribusi Lingkungan Kerja dan Disiplin Kerja Guru Terhadap Mutu Pembelajaran". In: *Edum Journal* 1.2 (Sept. 2018), pp. 121–132. doi: 10.31943/edumjournal.v1i2.16.
- [12] G. Vial. "Understanding Digital Transformation: A Review and a Research Agenda". In: *The Journal of Strategic Information Systems* 28.2 (June 2019), pp. 118–144. doi: 10.1016/j.jsis.2019.01.003.
- [13] L. Chen, P. Chen, and Z. Lin. "Artificial Intelligence in Education: A Review". In: *IEEE Access* 8 (2020), pp. 75264–75278. doi: 10.1109/ACCESS.2020.2988510.
- [14] D. Ifenthaler and J. Y.-K. Yau. "Utilising Learning Analytics to Support Study Success in Higher Education: A Systematic Review". In: *Education Tech Research Dev* 68.4 (Aug. 2020), pp. 1961–1990. doi: 10.1007/s11423-020-09788-z.
- [15] O. Zawacki-Richter, V. I. Marín, M. Bond, and F. Gouverneur. "Systematic Review of Research on Artificial Intelligence Applications in Higher Education – Where Are the Educators?" In: *International Journal of Educational Technology in Higher Education* 16.1 (Dec. 2019), p. 39. doi: 10.1186/s41239-019-0171-0.
- [16] M. F. Naen, M. H. Muhamad Adnan, N. A. Yazı, and C. K. Nee. "Development of Attendance Monitoring System with Artificial Intelligence Optimization in Cloud". In: *International Journal of Artificial Intelligence* 8.2 (Dec. 2021), pp. 88–98. doi: 10.36079/lamintang.ijai-0802.315.
- [17] I. Amirulloh, I. D. Iskandar, Y. Apriyani, A. I. Warnilah, D. S. Purnia, and M. Surahman. "Teacher Attendance Monitoring System Teaching with QR-Code and Geo Location Using Android Platform". In: *Journal of Physics: Conference Series* 1641.1 (Nov. 2020), p. 012030. doi: 10.1088/1742-6596/1641/1/012030.
- [18] A. B. Buchori, R. M. Dzul Ikrom, W. Wijayanto, and A. R. Rozzaqi. "Student Attendance Application for Class X Using QR Code to Improve Student Order". In: *Jurnal Sains dan Teknologi* 13.3 (Oct. 2024), pp. 374–382. doi: 10.23887/jstundiksha.v13i3.84500.
- [19] G. Falloon. "From Digital Literacy to Digital Competence: The Teacher Digital Competency (TDC) Framework". In: *Education Tech Research Dev* 68.5 (Oct. 2020), pp. 2449–2472. doi: 10.1007/s11423-020-09767-4.
- [20] J. Tondeur, R. Scherer, F. Siddiq, and E. Baran. "Enhancing Pre-Service Teachers' Technological Pedagogical Content Knowledge (TPACK): A Mixed-Method Study". In: *Computers in Human Behavior* 95 (2020), pp. 177–190. doi: 10.1016/j.chb.2019.11.007.
- [21] Dewi Rosmala, Muhammad Ichwan, Dicky Darmawan, Fadillah Muamar Fauzan, Agil Yudistira, and Mochamad Hafied Ibni Anwar. "Sistem E-Presensi Berbasis Web Dengan Kode QR di SMK Negeri 2 Cimahi". In: *DinSos* 1.3 (Aug. 2024), pp. 37–44. doi: 10.62951/dinsos.v1i3.493.
- [22] N. Prayogi and A. Ayuningtyas. "Aplikasi Presensi Kegiatan Menggunakan QR Code dan Digital Signature pada Dinas Kominfo Kabupaten Gresik". In: *JATI* 13.2 (June 2023), pp. 109–121. doi: 10.34010/jati.v13i2.9432.
- [23] I. D. Perwitasari, J. Hendrawan, N. A. Putri, and Y. T. Bilqis. "QR Code Based Attendance System as an Innovation for High School Management". In: *Journal of Informatics Management and Information Technology* 4.4 (2024), pp. 158–163. doi: 10.47065/jimat.v4i4.417.

- [24] N. Azizah, R. Jannah, R. Agus Wilantara, A. Fajri, and M. Rifqi A.H. "Sistem Presensi Menggunakan QR Code dan Google Spreadsheet di Sekolah Madrasah Ibtidaiyah di Desa Trebungan". In: *Mardika* 2.1 (Mar. 2024), pp. 25–33. doi: 10.55377/mardika.v2i1.9733.
- [25] Y. Aryo Bagaskoro and J. Wantoro. "Pengembangan Sistem Presensi Menggunakan QR Code Berbasis Website pada Siswa SMK". In: *Tekinkom* 8.1 (June 2025), p. 29. doi: 10.37600/tekinkom.v8i1.2091.
- [26] H. Crompton and D. Burke. "Artificial Intelligence in Higher Education: The State of the Field". In: *International Journal of Educational Technology in Higher Education* 20.1 (Apr. 2023), p. 22. doi: 10.1186/s41239-023-00392-8.
- [27] D. Nguyen. "Distributed Leadership in a Multicultural Context: Case Study from Vietnam-Finland International School". MA thesis. University of Jyväskylä, 2020.
- [28] F. Kamalov, D. Santandreu Calonge, and I. Gurrib. "New Era of Artificial Intelligence in Education: Towards a Sustainable Multifaceted Revolution". In: *Sustainability* 15.16 (Aug. 2023), p. 12451. doi: 10.3390/su151612451.
- [29] M. Khatun, R. Islam, S. Kumar, R. Hossain, and L. Mani. "The Impact of Artificial Intelligence on Educational Transformation: Trends and Future Directions". In: *Journal ISI* 6.4 (Dec. 2024), pp. 2347–2373. doi: 10.51519/journalisi.v6i4.879.
- [30] S. Strohmeier. "Digital Human Resource Management: A Conceptual Clarification". In: *German Journal of Human Resource Management* 34.3 (Aug. 2020), pp. 345–365. doi: 10.1177/2397002220921131.
- [31] J. H. Marler and J. W. Boudreau. "An Evidence-Based Review of HR Analytics". In: *The International Journal of Human Resource Management* 28.1 (Jan. 2017), pp. 3–26. doi: 10.1080/09585192.2016.1244699.
- [32] D. Vrontis, M. Christofi, V. Pereira, S. Tarba, A. Makrides, and E. Trichina. "Artificial Intelligence, Robotics, Advanced Technologies and Human Resource Management: A Systematic Review". In: *The International Journal of Human Resource Management* 33.6 (Mar. 2022), pp. 1237–1266. doi: 10.1080/09585192.2020.1871398.
- [33] P. Prinsloo. "Data Frontiers and Frontiers of Power in (Higher) Education: A View of/from the Global South". In: *Teaching in Higher Education* 25.4 (May 2020), pp. 366–383. doi: 10.1080/13562517.2020.1723537.
- [34] J. König et al. "The Links Between Pedagogical Competence, Instructional Quality, and Mathematics Achievement in the Lower Secondary Classroom". In: *Educational Studies in Mathematics* 107.1 (May 2021), pp. 189–212. doi: 10.1007/s10649-020-10021-0.
- [35] Y. K. Dwivedi et al. "Artificial Intelligence (AI): Multidisciplinary Perspectives on Emerging Challenges, Opportunities, and Agenda for Research, Practice and Policy". In: *International Journal of Information Management* 57 (Apr. 2021), p. 101994. doi: 10.1016/j.ijinfomgt.2019.08.002.
- [36] N. Selwyn. "The Future of AI and Education: Some Cautionary Notes". In: *European Journal of Education* 57.4 (Dec. 2022), pp. 620–631. doi: 10.1111/ejed.12532.
- [37] I. Kampoowale, A. M. Hussien Musa, A. A. Adam Abdalla, H. Iftikhar, A. A. E. Abdelraheem, and Y. A. Elamin Elboukhari. "Assessing the Mediating Role of Human Capital in the Relationship Between Digital Transformation and Firm Performance". In: *Journal of Manufacturing Technology Management* 37.1 (Jan. 2026), pp. 1–22. doi: 10.1108/JMTM-02-2025-0122.
- [38] R. Scherer, F. Siddiq, and J. Tondeur. "The Technology Acceptance Model (TAM): A Meta-Analytic Structural Equation Modeling Approach to Explaining Teachers' Adoption of Digital Technology in Education". In: *Computers & Education* 128 (Jan. 2019), pp. 13–35. doi: 10.1016/j.compedu.2018.09.009.
- [39] O. Viberg, M. Hatakka, O. Bälter, and A. Mavroudi. "The Current Landscape of Learning Analytics in Higher Education". In: *Computers in Human Behavior* 89 (Dec. 2018), pp. 98–110. doi: 10.1016/j.chb.2018.07.027.

- [40] W. Matcha, N. A. Uzir, D. Gasevic, and A. Pardo. "A Systematic Review of Empirical Studies on Learning Analytics Dashboards: A Self-Regulated Learning Perspective". In: *IEEE Transactions on Learning Technologies* 13.2 (Apr. 2020), pp. 226–245. doi: 10.1109/TLT.2019.2916802.
- [41] M. Saqr and S. López-Pernas. "The Longitudinal Trajectories of Online Engagement Over a Full Program". In: *Computers & Education* 175 (Dec. 2021), p. 104325. doi: 10.1016/j.compedu.2021.104325.
- [42] S. Pramesti and P. Tri Febrianto. "Implementasi Sistem Absensi Digital untuk Meningkatkan Efisiensi Pencatatan Kehadiran Guru di Sekolah Dasar". In: *JATI* 8.2 (Apr. 2024), pp. 2429–2434. doi: 10.36040/jati.v8i2.9521.
- [43] S. Siamah and N. Nasruddin. "Pengembangan Smart Presensi Online Siswa Berbasis QR Code Terintegrasi Orang Tua untuk Meningkatkan Efisiensi Kinerja Guru SMA di Kabupaten Dompu". In: *JPM* 15.3 (Sept. 2025), pp. 1480–1485. doi: 10.37630/jpm.v15i3.3506.
- [44] Laila Nur Fadhillah, Sigit Auliana, and Gagah Dwiki Putra Aryanto. "Perancangan Sistem Absensi Siswa Berbasis Web Menggunakan QR Code di Sekolah PAUD Amelia Darul Akhyar Cikande". In: *Jatilima* 7.02 (July 2025). doi: 10.54209/jatilima.v7i02.1530.
- [45] M. Bond and S. Bedenlier. "Facilitating Student Engagement Through Educational Technology: Towards a Conceptual Framework". In: *Journal of Interactive Media in Education* 2019.1 (Sept. 2019), p. 11. doi: 10.5334/jime.528.
- [46] A. Haleem, M. Javaid, M. A. Qadri, and R. Suman. "Understanding the Role of Digital Technologies in Education: A Review". In: *Sustainable Operations and Computers* 3 (2022), pp. 275–285. doi: 10.1016/j.susoc.2022.05.004.
- [47] J. J. Sosa-Alonso, V. M. Hernández Rivero, A. L. Sanabria Mesa, and A. Bethencourt Aguilar. "Adoption of Digital Educational Resources by Early Childhood Education Teachers: A Fad or a Conviction?" In: *Computers & Education* 238 (Dec. 2025), p. 105396. doi: 10.1016/j.compedu.2025.105396.
- [48] B. Shambare and T. Jita. "Mobile Learning Acceptance Among Pre-Service Teachers in the Global South: A TPACK-Based Structural Equation Modelling Approach". In: *Computers and Education Open* 10 (June 2026), p. 100373. doi: 10.1016/j.caeo.2026.100373.
- [49] S. Sharma, G. Singh, C. S. Sharma, and S. Kapoor. "Artificial Intelligence in Indian Higher Education Institutions: A Quantitative Study on Adoption and Perceptions". In: *International Journal of System Assurance Engineering and Management* (Jan. 2024). doi: 10.1007/s13198-023-02193-8.
- [50] M. A. Toha. "Artificial Intelligence, Sustainability and Higher Education: A Systematic Literature Review Toward Sustainable Higher Education (SHE) Framework". In: *International Journal of Educational Management* 40.1–2 (Mar. 2026), pp. 29–52. doi: 10.1108/IJEM-12-2024-0773.
- [51] J. Liu and X. Xian. "Impact of Digital Transformation on High-Quality Economic Development: The Mediating Role of Human Capital Investment". In: *Finance Research Letters* 86 (Dec. 2025), p. 108657. doi: 10.1016/j.frl.2025.108657.
- [52] M. Díaz-Fernández, J. C. Rivera-Prieto, and Á. López-Cabrales. "Digital Transformation and Social Sustainability: The Mediating Role of Employees' Digital Competencies". In: *Technovation* 156 (Aug. 2026), p. 103607. doi: 10.1016/j.technovation.2026.103607.