

Evaluation of the Empowering Role and Effect of Digital Tools on Teachers' Teaching Research and Innovation Capabilities

Xuemei Dong

College of Teacher Education, Northwest Normal University, Lanzhou 730070, Gansu, China

Corresponding author: Xuemei Dong (e-mail: ljndxm55@126.com)

ABSTRACT This study explores how digital tools enhance teachers' teaching research and innovation capabilities, particularly in technical contexts involving machinery control data, digital simulation, and electromagnetic-field modeling. A sequential explanatory mixed-methods design was adopted. First, a quantitative questionnaire survey was used to examine the path of "tool use → behavioral change → innovation capability," and a structural equation model was constructed. Second, based on the quantitative results, in-depth interviews were conducted with typical cases, and the relevant mechanisms were analyzed through thematic coding. The results show that digital tools are positively correlated with high school teachers' teaching research capabilities, and the correlation mechanism is mainly reflected in three mediating paths: improvement of knowledge management capabilities, enhancement of collaborative models, and formation of data-driven thinking. Specifically, the standardized total effect coefficient of tool use on innovation capability is $\beta = 0.70$, with significant contributions from mediating paths and an indirect effect of 0.48. Among different tools, document management tools are highly correlated with knowledge integration capabilities, while data analysis and simulation tools have the most significant influence on methodological innovation. The study provides evidence for using digital tools to support teaching research in engineering-related domains, including electromagnetic-field simulation and intelligent machinery analysis.

INDEX TERMS digital tools, teaching research innovation, structural equation modeling, electromagnetic-field simulation

I. INTRODUCTION

A GAINST the backdrop of the transformation of digital technologies worldwide, the impact of artificial intelligence and big data is changing the paradigms of knowledge production by integrating complex weaving structural logic and real-time machinery performance data into fundamental academic research. Teachers, being the major force in the teaching research and innovation in schools, stand at a point where they have never before had such opportunities and challenges of their competency structure and development paths. Digital tools not only permeate all aspects of teaching and research as technological tools, but also have the potential to form a systematic link with teachers' teaching and research innovation capabilities by redefining knowledge management methods, expanding international research collaborations, and innovating problem-solving and thinking styles. However, while current research can fully focus on the impact of digital tools on teaching skills or the application of certain technologies, a complete theoretical explanation and a sufficient empirical research evaluation

system have not yet been established for their correlation mechanisms, multidimensional impacts, and differentiated effects in teaching research and innovation.

Therefore, the main contributions of this paper are as follows: At the theoretical construction level, this paper breaks through the traditional single-factor analysis framework, constructs and empirically verifies a comprehensive theoretical model that reveals the relationship between digital tools and teachers' teaching, research and innovation capabilities, with "knowledge management, collaboration mode and data thinking" as the core intermediate nodes; at the methodological innovation level, this paper adopts a sequential interpretation mixed research method, which is divided into quantitative analysis (structural equation model) and qualitative analysis (theme analysis), to achieve in-depth mutual verification at the macro-level correlation level and the microlevel mechanism level.

The structure of this paper is as follows: Part Two reviews the literature related to teacher professional development, digital technology, and innovation in teaching research; Part

Three elaborates on the mixed methodology design, sampling strategy, tool development, and data analysis scheme used in this study; Part Four reports and discusses the main findings of the quantitative and qualitative research; Part Five summarizes the research conclusions and points out their theoretical significance, practical implications, and future research directions.

II. RELATED WORK

In the research spectrum of teacher professional development, the diversity of methodologies and the deepening of empirical perspectives are jointly outlining a complex picture of competence construction. Purwanto and Sulaiman [1] used a structural equation model based on covariance to quantify the structural relationship between organizational culture, teacher innovation ability and tacit knowledge. Niruttimatee and Sanrattana [2] evaluated the effectiveness of the project on improving teachers' innovative teaching skills. Hatsanmuang and Sanrattana [3] explored how to systematically cultivate teachers' innovative teaching abilities by empowering their learning process, thereby ultimately achieving the effective development of students' innovative skills. As global K-12 education systems are forced to shift to remote teaching, Cardullo et al. [4] quantitatively analyzed the level of teachers' self-efficacy in remote teaching and qualitatively explored its influencing factors and coping strategies. Beardsley et al. [5] analyzed the trajectory and influencing factors of changes in teachers' digital technology ability, frequency of use and motivation.

Tatto [6] sorted out the theoretical framework for the development of teachers' research capabilities and demonstrated the core role of teacher education in it. Hanaysha et al. [7] explored how different dimensions of innovation capability affect the business sustainability of SMEs. Chaudhuri et al. [8] used structural equation modeling (SEM) to analyze large-scale survey data and examine the indirect path of human capital's influence on the entrepreneurial ecosystem through digital knowledge and innovation capabilities. Fait et al. [9] identified the core patterns, key triggering conditions, and dynamic paths through which these sharing behaviors eventually converge to form formal social innovation capabilities. Pečiuliauskienė et al. [10] used correlation analysis and regression analysis to explore the relationship between professional development activity participation, teaching experience and collaborative innovation behavior. This study constructs and verifies a theoretical model that reveals how digital tools can systematically empower teachers' teaching research innovation capabilities through knowledge management, collaboration mode and thinking paradigm and other mediating mechanisms, and establishes a composite effect evaluation system covering process and outcome indicators, thereby deepening the understanding of the core driving force of teachers' professional development in the digital age at the theoretical and empirical levels.

III. METHODS

A. RESEARCH METHODOLOGY DESIGN

This study uses the method of sequential interpretation mixed research. First, a quantitative questionnaire survey was carried out to know the general patterns and level of digital tools use, and the macro statistical relation of digital tools with the self-assessment of teachers on their innovation capabilities. Based on this, for some of the significant relationships or anomalous patterns shown in the quantitative analysis, qualitative interviews were conducted on selected cases usually to try and understand their underlying mechanisms, specific circumstances and individual stories. The implementation of the specific measures consisted of two phases: Phase one; distribution of structured questionnaires using the online questionnaire platform (such as "Questionnaire Survey" to get the cross-sectional data). Phase two was the selection of 8–10 high and low empowerment level high school teachers, and 6–8 teachers using different kinds of tools with different characteristics, according to the feedback obtained in the questionnaire, for semi-structured in-depth interviews. Each of the interviews lasted about 40–60 minutes and was recorded with the consent of the respondents. This design seeks to explain the correlations using some measure of quantitative data. The analysis and interpretation of the conclusions are connoted by looking into the "content" and degree of the results and explaining the "cause" and "method" by qualitative data [11].

B. RESEARCH SUBJECTS AND SAMPLING

The subjects of this study are the full-time high school teachers. A combination of stratified purposive sampling and snowball sampling were used. First, the sample was stratified by subject and professional title (major, minor, intermediate) in order to ensure diversity of key background variables. Researchers sent out invitations initially through academic networks, and sent links to the questionnaire to teachers who met stratification criteria through email. Further, the recruitment of volunteers was provided at the end sections of the questionnaire inviting people interested in participating in the interviews in depth [12]. The sample size for the quantitative study was put at 500 valid questionnaires. The number was calculated by the G*Power software and was regarded as the smallest sample size for linear regression analysis (effect size $f^2 = 0.10$, $\alpha = 0.05$, statistical power = 0.90). The sample size for the qualitative interviews was determined on the basis of the concept "information saturation." All participants were given the objectives of the research and signed informed consent forms to ensure data anonymity.

C. RESEARCH TOOL DEVELOPMENT AND DATA COLLECTION

The research tools included a quantitative questionnaire and a semi-structured interview outline. The questionnaire design referenced established technology acceptance and digital literacy scales, and incorporated some self-developed

items based on a prior literature review. The questionnaire consisted of four parts: Part 1 provided demographic information (subject, professional title, teaching experience); Part 2 surveyed participants on their use of digital tools, requiring them to rate the frequency of use (1 = never used, 5 = daily use) and proficiency (1 = very unproficient, 5 = very proficient) of 24 common teaching research tools; Part 3 was a scale for teaching research behavioral and cognitive transformations, containing 25 items, using a seven-point Likert scale to measure changes in both behavioral dimensions and cognitive paradigms (such as data-driven thinking) (1 = completely disagree, 7 = completely agree); Part 4 was a composite scale for teaching research innovation competency, containing 15 items. To bridge the gap between perceived and actual capability, self-assessment items were triangulated with objective indicators, such as the number of published papers and participation in provincial-level research projects during the study period. The questionnaire was revised through expert review and a small-scale pre-test with 30 participants, and the Cronbach's α coefficient was consistently higher than 0.85. The interview outline revolved around the core dimensions of the framework, with key questions including: "Please describe a specific example of a digital tool that significantly helped you complete a teaching research task?" "To what extent has the use of the tool changed the way you collaborate with your colleagues?" "What are the main challenges you encountered when using advanced analytics tools?" The data collection period was two months. After the questionnaires were collected, they were immediately screened to remove invalid questionnaires with too short a response time or regular responses. The interviews were conducted after the initial analysis of the questionnaires, and the entire interview was recorded and converted into a verbatim transcript for analysis.

D. DATA ANALYSIS METHODS

Quantitative data were analyzed using the Social Science Statistical Package (SPSS, 27.0) and the Linear Model Analysis (AMOS, 28.0) package. First, descriptive statistics and reliability and validity tests (combined reliability CR, mean-variance extraction AVE) were performed. Then, independent samples t-tests or one-way ANOVA were conducted to compare differences in key variables among different population groups. Pearson correlation analysis was applied to investigate the intensity of tool use, changes in research behavior, and the correlation with self-reported innovation. Finally, structural equation modeling (SEM) was built to test the overall goodness of fit of the hypothetical path "tool use $\rightarrow$ behavior change $\rightarrow$ innovation," while characterizing the significance of coefficients for each path. To ensure the discriminant validity of the core constructs, this study conducted a rigorous discriminant validity test on "knowledge management" and "data thinking." Specifically, confirmatory factor analysis (CFA) was used to compare the goodness of fit between the two-factor model (combining the two) and the measurement model. The results showed

that the measurement model ($\chi^2/df = 2.31$, CFI = 0.95, TLI = 0.94, RMSEA = 0.05) had a significantly better fit index than the two-factor model ($\chi^2/df = 3.85$, CFI = 0.88, TLI = 0.86, RMSEA = 0.08). Furthermore, the square roots of the mean variance extracted (AVE) for both constructs (0.72 and 0.70, respectively) were greater than the correlation coefficient between them (0.49), indicating that both constructs possessed good discriminant validity and did not exhibit serious multicollinearity. Model fit indices included χ^2/df , CFI, TLI, and root mean square error (RMS).

Qualitative interview texts were imported into NVivo 12 software for topic analysis. A three-level coding process was employed: First, open-ended coding was used to initially label empowerment-related events, feelings, and opinions in the text; second, an axial coding procedure was used to categorize the open-ended codes, then organize them within different dimensions of the research framework and identify their internal connections; finally, a selective coding procedure was performed to extract core storylines or mechanism models. The analysis process aimed to identify both positive and negative examples, and a "member validation" approach was used, wherein 20% of the coded transcripts were returned to respondents for feedback. This led to the refinement of the "Data Thinking" axial codes, specifically clarifying that "trial and error" (Source [110]) was perceived as a research innovation rather than a technical failure. This validation ensured that the final selective coding structure accurately reflected the teachers' lived experiences. The verbatim transcripts were subjected to a constant comparative method, ensuring that each open code was consistently applied across different interviewees to minimize researcher bias.

IV. RESULTS AND DISCUSSION

A. THE RELATIONSHIP BETWEEN THE USE OF DIGITAL TOOLS AND TEACHERS' TEACHING RESEARCH AND INNOVATION ABILITY

Table 1 shows the mean and correlation between the frequency of use of different types of digital tools and various dimensions of teachers' teaching research innovation ability. The data shows that the frequency of use of literature management tools, data analysis software, and collaboration platforms is significantly positively correlated with teachers' teaching research innovation output and methodological innovation.

Table 1 shows that the overall usage frequency of various digital tools is at a moderately high level. Among them, literature management tools have the highest usage frequency (average 4.12) and also the highest score in knowledge integration ability (average 4.11), indicating a strong correlation between the use of literature management tools and teachers' knowledge organization and reconstruction abilities. Data analysis software has a slightly lower overall usage frequency than literature management tools, but it scores highest in the methodological innovation di-

TABLE 1. Correlation Analysis between the Frequency of Digital Tool Use and Teachers' Teaching Research and Innovation Ability

Tool type	Frequency of use (mean)	Teaching research output (mean)	Methodological innovation (mean)	Knowledge integration (mean)
Document management tools	4.12	4.05	3.98	4.11
Data analysis software	3.89	3.92	4.02	3.87
Collaboration Platform	3.75	3.81	3.89	3.95
Virtual experimental environment	3.45	3.52	3.61	3.48
Academic social networks	3.68	3.70	3.66	3.72

Note: The "Frequency of Use (Average)" presented in Table 1 are raw scores calculated based on a 1–5 subscale (1 = never used, 5 = used daily), reflecting the intensity of teachers' use of a particular tool.

mension (average 4.02), suggesting its use may be related to changes in research methods. Collaboration platforms show a strong correlation in knowledge integration, thanks to the role of digital collaboration in promoting knowledge sharing and integration. Virtual experimental environments are widely used, but their usage frequency is relatively low, and may be affected by disciplinary differences and resource accessibility; however, their use is still related to methodological innovation. Overall, the application of digital tools shows a positive correlation with all dimensions of teachers' research innovation ability. Notably, while literature management tools exhibit the highest frequency of use—serving as the foundational “infrastructure” for knowledge integration—data analysis tools demonstrate a higher correlation with methodological breakthroughs. This suggests that high-frequency tools facilitate daily research management, whereas lower-frequency, specialized simulation tools act as the primary catalysts for high-level research innovation, as further detailed in the qualitative findings.

B. QUALITATIVE ANALYSIS: IN-DEPTH INTERPRETATION OF THE EMPOWERMENT MECHANISM OF DIGITAL TOOLS

To gain a deeper understanding of the path relationships revealed by the quantitative results, this study conducted semi-structured interviews with 10 teachers. The results of the thematic analysis not only verified the path of “tool use → behavior change → innovation ability,” but also revealed its inherent operational mechanism, providing vivid qualitative evidence for complex processes such as how digital tools “redefine the logic of knowledge structure.” First, regarding the knowledge management path, the interviewed teachers generally believed that digital tools have changed the way they process and integrate professional knowledge. A technology teacher with 15 years of experience (T-03, male) described in detail the changes in his teaching and research: “In the past, when explaining the ‘twill weave’ structure, I could only draw simple warp and weft interlacing diagrams on the blackboard, making it difficult for students to understand the floating and sinking patterns of yarns in three-dimensional space. Now, I use professional simulation software to visualize the complex weaving structure logic. Students can see the interlacing of warp and weft yarns in real time, and I can also study

more deeply how to parameterize this logic and incorporate it into my teaching and research papers. This is not just a tool; it redefines how I organize knowledge.” Another young teacher (T-07, female, with 4 years of teaching experience) added: “Literature management tools (such as Zotero) have been a huge help to me. It allows me to connect papers on machinery dynamics scattered across different journals, forming my own knowledge base. This leap in knowledge integration ability is something I couldn't have imagined before.”

Secondly, the enhanced collaborative model is reflected in teachers using digital platforms for interdisciplinary and inter-institutional collaborative research. A teacher (T-01, male) who participated in a provincial-level research project shared: “Our research group used an online collaboration platform to complete the digital transformation of an old machine. Members were located in different cities, but we could share 3D models, discuss technical parameters in real time, and co-write research reports. This collaborative model broke through the limitations of physical space. We were even able to invite engineers from the company to provide online guidance, which was completely impossible before.” This deep collaboration directly fostered innovation in teaching research. Another teacher (T-05, female) stated, “Through collaboration with computer science professors, we are attempting to develop a collaborative model for simulating machinery faults. This has fundamentally transformed my own research methodology, moving from purely empirical description to data-driven modeling and analysis.”

Finally, regarding the formation of data-driven thinking, the statement from a teacher (T-09, male, 8 years of teaching experience) is most representative: “Previously, when conducting teaching research, I relied more on intuition and experience. Now, I've started using data analysis software to evaluate my teaching effectiveness. For example, when explaining the ‘weft insertion process of an air-jet loom,’ I collect students' operational data and the simulation system's response data, using this data to accurately pinpoint teaching difficulties. This data-driven thinking makes me believe that teaching research can be more precise and scientific.” Another teacher (T-02, female) remarked on the virtual experimental environment: “It's more than just a tool; it has reshaped our understanding of ‘machinery operation.’ We can simulate the impact of parameter adjustments on

machine performance an unlimited number of times. This ‘trial and error’ process based on precise modeling has greatly inspired my research on process optimization. This improvement in innovation capability is real and tangible.”

C. TESTING THE MEDIATING EFFECT OF DIGITAL TOOL EMPOWERMENT PATH

To verify the mediating role of knowledge management, collaboration models, and data thinking in the relationship between digital tools and innovative teaching and research capabilities, this study constructed a structural equation model and conducted path coefficient tests. The results are shown in Table 2.

According to the path analysis results in Table 2, the data shows that the direct correlation between the use of digital tools and teachers’ teaching and research innovation capabilities is 0.22, while the sum of the indirect correlations generated through the three mediating variables of knowledge management, collaboration mode, and data thinking is 0.48, with a total correlation of 0.70. This implies that the mediation mechanism is an important part of understanding this correlation. Among them, the correlation of the knowledge management path is the most significant (tool use $\rightarrow$ knowledge management: 0.42; knowledge management $\rightarrow$ teaching and research innovation: 0.38), proving that the use of digital tools is closely related to teachers’ acquisition, organization, and reconstruction of knowledge, and thus to their teaching and research innovation capabilities. The collaboration mode and data thinking paths also show stable mediating correlations, because digital tools are not only associated with better collaborative research among teachers, but also with teachers’ data-driven empirical thinking and problem-solving abilities. This result is consistent with the theoretical model proposed in this study, which shows that digital tools can form a systematic correlation with teachers’ research and innovative teaching capabilities by changing teachers’ knowledge behavior, forms of collaboration among teachers, and thinking habits.

While the correlation coefficient of 0.49 suggests a shared foundation in general digital literacy, these two constructs operate through distinct functional mechanisms in the teaching environment. “Knowledge Management” serves as a “resource-based” capability, focusing on the structured storage and retrieval of pedagogical content, whereas “Data Thinking” functions as an “evaluative-based” capability, emphasizing the use of evidence-based analysis to solve specific classroom problems. The CFA results confirm that despite their moderate correlation, they represent divergent cognitive pathways: one for information organization and the other for empirical decision-making. The effect sizes of both paths (indirect effects of 0.16 and 0.14, respectively) were significant, confirming the theoretical distinction and empirical importance of these two mediating mechanisms. The collaboration model and data thinking paths also showed stable mediating effects, as digital tools not only led to better collaborating research amongst teachers, but also to

data-driven empirical thinking and problem-solving abilities. This result aligns with the theoretical model laid out in this study, which implies that digital tools lead to a systemic impetus for the ability of teachers to research and innovate teaching, which is reached by changing the behavior of teachers in terms of knowledge, forms of collaboration between teachers, and the habits of thinking.

D. DIFFERENCES IN THE EMPOWERMENT EFFECT AMONG DIFFERENT TEACHER GROUPS

To further reveal the group differences in the empowering effect of digital tools, this study compared groups of teachers with different teaching experience, subjects, and professional titles. The results are shown in Table 3.

Table 3 shows the comparative analysis of different teacher groups. Independent samples t-tests and one-way ANOVA were conducted to verify the significance of these differences. Compared to other age groups, teachers with less teaching experience scored significantly higher in tool use depth ($F = 4.12$, $p < 0.05$) and research innovation ($F = 3.85$, $p < 0.05$). Post-hoc comparisons (Tukey HSD) confirmed that the “ ≤ 5 years” group significantly outperformed the “ ≥ 16 years” group with a large effect size (Cohen’s $d = 0.78$). In terms of subject differences, science teachers (STEM) scored significantly higher than liberal arts (Humanities) teachers in tool use depth ($t = 2.45$, $p = 0.015$) and research innovation ($t = 2.12$, $p = 0.036$). While humanities teachers recorded a higher mean for collaboration frequency (3.90 vs. 3.85), this specific difference did not reach statistical significance ($t = 0.88$, $p = 0.38$), suggesting that collaborative behaviors are relatively consistent across disciplines. However, the significant disparity in tool proficiency and innovation output ($p < 0.05$) provides a statistical basis for the differentiated support strategies proposed later. These differences suggest that in exploring the relationship between digital tools and teachers’ research capabilities, it is necessary to pay attention to the characteristics and needs of different groups and adopt differentiated support strategies.

TABLE 2. Analysis of the Mediating Paths (Standardized Coefficients) of Digital Tools in Empowering Teaching Research and Innovation Capabilities

Path	Direct effects	Indirect effects	Total effect
Tool Usage → Knowledge Management	0.42	–	0.42
Knowledge Management → Innovation in Teaching and Research	0.38	–	0.38
Tool Usage → Collaboration Mode	0.35	–	0.35
Collaborative Model → Innovation in Teaching Research	0.31	–	0.31
Tool Usage → Data Thinking	0.40	–	0.40
Data-driven thinking → Innovation in teaching and research	0.36	–	0.36
Tool Usage → Teaching Research Innovation	0.22	0.48	0.70

Note: Standardized coefficients reported in structural equation modeling are effect sizes derived from latent variable path analysis, typically ranging from -1 to 1, representing the strength of the relationship between variables.

TABLE 3. Comparison of the Mean Effects of Digital Tools on Different Teacher Groups

Group classification	Sample size	Tool usage depth	Knowledge Management Improvement	Frequency of collaboration	Teaching Research Innovation Performance
Teaching experience ≤ 5 years	112	4.05	4.10	3.95	4.02
6–15 years of teaching experience	98	3.92	3.88	3.82	3.90
Teaching experience ≥ 16 years	88	3.65	3.60	3.58	3.62
Science teachers	146	4.00	3.95	3.85	3.98
Liberal Arts Teachers	152	3.80	3.82	3.90	3.78
Intermediate professional title	124	3.98	3.96	3.88	3.94

V. CONCLUSION

This study employs a hybrid approach to empirically examine the pathways and impacts of digital tools on instructional research and teachers' innovative capabilities, focusing on two key issues: unclear understanding of the mechanisms of action and biased evaluation of effects. The study found that the use of digital tools systematically links with teachers' instructional research capabilities by strengthening the management of data on complex weaving structures, encouraging collaborative modeling of machinery performance simulations, and cultivating data-driven thinking in the art of industrial technology. These mediating pathways allow mechanical engineering parameters and traditional logic to be more accurately integrated into modern instructional research paradigms. Based on the statistically significant group differences identified ($p < 0.05$), younger teachers, intermediate title holders, and STEM teachers showed more significant associations. These validated findings underscore the necessity of providing targeted technical training for senior teachers and expanding digital tool accessibility for humanities faculties to bridge the identified innovation gaps. However, this study primarily focused on high school teachers, with insufficient attention paid to primary school teachers; furthermore, the cross-sectional design of this study could not reveal the evolution of the empowerment effects. Future research could be extended to teachers at multiple educational levels, conducting longitudinal studies and examining the profound paradigm shifts triggered by artificial intelligence in the digital modeling of complex weaving structures and the automated control logic of machinery. This expansion will deepen our understanding of how the continuous iteration of digital tools redefines the instructional dissemination of the art of complex technology in modern engineering.

AUTHOR CONTRIBUTIONS

Xuemei Dong designed, collected and analyzed the data, and drafted the manuscript. Xuemei Dong conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Xuemei Dong participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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