

Mechanisms and Limits of Digital Process Visualization in Brush-Calligraphy Copying in Primary and Secondary Schools

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ABSTRACT

Digital sensing and video recording preserve trajectory, velocity, pressure, and brush posture, making transient brush movements available for classroom review and comparison. Visibility alone does not establish motor competence. Through a problem-oriented narrative synthesis and conceptual analysis, this study compares six core empirical sources retrieved through August 8, 2026, by participants, writing tasks, process measures, feedback design, and retention or transfer evidence. The literature suggests that process visualization can support joint observation, problem localization, and feedback dialogue. Studies involving adults, other writing systems, or ordinary pen handwriting offer evidence about possible mechanisms but cannot establish overall effectiveness in school-based Chinese brush calligraphy. The proposed framework distinguishes process recording, diagnostic evidence, regulatory evidence, and learning evidence.

INTRODUCTION

The Guidelines for Calligraphy Education in Primary and Secondary Schools lists copying models, appreciation, and writing practice as essential components of curriculum implementation, requiring students to develop aesthetic abilities and cultural understanding through standardized writing (Ministry of Education, 2013). A 2024 notice from the General Office of the Ministry of Education on strengthening standardized Chinese character writing education in primary and secondary schools proposes exploring new avenues empowered by digital technology, while simultaneously emphasizing interest cultivation, writing habits, and motivational assessment (General Office of the Ministry of Education, 2024). Rather than treating device usage per se as a measure of curriculum effectiveness, these policy texts situate digital technology within authentic writing activities. The educational value of technology ultimately depends on whether it can improve students' processes of observing models, understanding brushwork, and adjusting their copying.

Existing literature has discussed the curricular nature of calligraphy education and its direction for digital transformation. Curriculum studies distinguish between handwriting instruction and calligraphy education, emphasizing that technical training must be linked to aesthetic experience and cultural understanding (Song, 2015). Discussions on digital transformation involve educational orientation, technological bottlenecks, and outcome evaluation, requiring that technology application be subordinate to teaching quality (Liu & Zhang, 2025). These findings establish value criteria for integrating technology into the classroom; however, analyses mostly focus on curriculum positioning or systemic reform, with limited discussion on how screen-based information alters students' observation, motor actions, and subsequent writing within a single copying activity. Engineering research has already achieved the acquisition and visualization of trajectories, pressure, and posture. The challenge for educational research is no longer merely whether recording is possible, but under what conditions the recorded information can serve as a learning resource.

This paper examines how digital process visualization supports brush copying, under what conditions feedback can inform motor adjustment, and what evidence is needed to assess retention and transfer. It proposes an analytical framework that distinguishes process recording, diagnostic evidence, regulatory evidence, and learning evidence to clarify what different studies can establish.

THEORETICAL REVIEW

Digital process visualization" refers to capturing temporal and kinematic information during writing via video, sensors, or computational models, and then translating this data into visual representations that can be reviewed, identified, and compared. The scope of discussion is limited to brush copying in primary and secondary schools; standardized hard-pen writing, calligraphy appreciation platforms, and general digital resource development are referenced only when they can elucidate similar mechanisms. Embodied learning and technology-mediated research provide the conceptual foundation for this analysis (Jin & Cai, 2023; Wang, 2018; Yang, 2022), focusing on how external

representations participate in observation, motor regulation, and feedback, rather than using device novelty as a value judgment.

Motor learning research has not demonstrated that any single medium or feedback format is universally effective across different tasks. In a review of visual, auditory, haptic, and multimodal augmented feedback, Sigrist et al. (2013) noted that effectiveness varies depending on the combination of motor skill, learning stage, feedback strategy, and sensory channel, and that related research often focuses on simple or artificial tasks. Whether feedback is intuitive or information-rich merely describes presentation characteristics and cannot independently explain learning value. Judging its applicability in a calligraphy classroom requires examining whether students can understand the prompts, alter their movements accordingly, and maintain performance after the prompts are removed.

METHODOLOGY

This study employs a problem-oriented narrative literature synthesis and conceptual analysis. The literature search was conducted up to August 8, 2026. Policy and regulatory materials were sourced from the websites of the Ministry of Education and judicial administrative departments. Chinese-language research was retrieved through the CNKI journal portal and official journal websites, while English-language research was cross-verified through platforms including Crossref, PubMed, ACM, IEEE, Springer, Elsevier, PLOS, SAGE, and APSCE. Chinese search terms included "中小学书法教育" (primary and secondary school calligraphy education), "数字书法" (digital calligraphy), "书法学习系统" (calligraphy learning system), "毛笔临写" (brush copying), "书写反馈" (writing feedback), and "形成性评价" (formative assessment). English search terms included Chinese calligraphy learning, calligraphy training system, process visualization, handwriting feedback, motor learning, and formative assessment. Searches were further supplemented with author names and system names based on representative studies.

Material screening centered on whether process representations could be integrated into writing learning. Empirical studies considered for comparison directly addressed process acquisition, feedback presentation, writing experience, retention, or transfer, with priority given to peer-reviewed literature that clearly described samples, tasks, and results. Materials that merely discussed character generation, resource display, or general digital aesthetic education without addressing the writing learning process were excluded. A total of 29 items, comprising policies, regulations, standards, and academic literature, were ultimately included. For studies with empirical components that directly impacted the core arguments, the following were further extracted: research subjects and samples, tasks and writing tools, process indicators, feedback methods, immediate outcomes, retention or transfer tests, and the contextual proximity to brush copying in primary and secondary schools. Six representative studies are presented in Table 3. Due to significant variations in research subjects, writing systems, and measurement metrics, pooling effect sizes was inappropriate; thus, the analysis focuses on which specific links in the evidence

chain each study actually supports. The conceptual analysis considers four related teaching activities: process visualization, problem interpretation, motor adjustment, and brush-and-paper verification.

RESULTS

This section presents the findings of the narrative synthesis and conceptual analysis.

Pedagogical Representation of the Brushwork Process

Copying from a model takes the completed character form as the object of observation. While the paper preserves the morphology of strokes, structural relationships, and compositional order, the sequence of initiating, executing, and concluding strokes—as well as the speed of brush movement, the pressure applied, and the adjustments of the brush tip—disappear as the action ends. Although live teacher demonstrations can reveal these dynamic changes, students must still identify the movements, link them to the resulting marks on paper, and memorize the key points within a very short time. Lacking relevant experience, beginners often have to guess the process based solely on the final contour, oversimplifying problems caused by the interplay of brush tip, speed, and force into mere judgments of whether the result "looks like" the model or not.

The development of digital calligraphy training systems has gradually shifted the research focus from result simulation to the action process. Early haptic training systems recorded and reproduced the teacher's brush strokes and applied force (Nishino et al., 2011). Projection-based systems superimposed cues regarding position, speed, pressure, and brush handle orientation onto the writing area (Narita & Matsumaru, 2015), while subsequent solutions integrated motion sensing, trajectory generation, and playback (Matsumaru & Narita, 2017). CalliSense utilizes video, inertial, and pressure sensors to organize brush posture, finger pressure on the brush handle, and rhythm into information that teachers and students can jointly inspect (Gong et al., 2025). Finger pressure on the handle is not a direct measure of brush-tip pressure on the paper. Despite differing technical approaches, these systems address a consistent pedagogical problem: how to preserve fleeting movements during brushwork so that they remain available for observation and discussion even after the writing is completed.

Process recording expands the materials available for classroom use. Slow-motion and multi-angle video extend the observation time for key movements; trajectory or pressure curves mark continuous changes as locatable segments; and consecutive writing records provide concrete objects for comparison. Teachers can pinpoint the exact moment of initiation, execution, turning, or conclusion when a stroke appears stiff. Students can also cross-reference the changes shown on the screen with the lines on paper and their own tactile sensations at the time. At this stage, visual representations primarily serve the functions of guiding attention and locating problems. Whether they enter the teaching process depends not on the volume of information, but on whether the presented changes correspond to the specific difficulties the student is currently facing.

Unfiltered process information does not naturally become teaching content. A complete video recording contains many movement details, and a single pressure curve may exhibit multiple fluctuations; without a clear observation question in the classroom, new information may increase cognitive load without clarifying the writing difficulty. Teachers need to select relevant segments based on specific changes in the strokes, linking the moments in the video, the positions on paper, and the movements the student can physically feel. Once teachers and students share a common reference, vague criticisms like "incorrect force" or "poor rhythm" can be transformed into specific problems that can be observed, discussed, and re-attempted.

After jointly identifying a discrepancy, students must still judge whether it constitutes the cause of the current problem. A discrepancy between a demonstrated trajectory and a personal trajectory does not directly imply a specific movement error; judgments must incorporate the traces on paper, the physical sensations during writing, and other process variables. After completing these cross-checks, students propose a movement adjustment for the next attempt and use the new brush-and-paper result to test their original hypothesis. If the result meets expectations, the hypothesis receives temporary support; if the result remains unchanged, the student should first check whether the intended adjustment was made, then re-examine the cause or task difficulty as needed. Digital representations can help learners locate and test problems, yet expert movements must still be reorganized by the learner within the context of real materials. Consequently, the teacher's role shifts from simply adjudicating the outcome to selecting evidence, probing for causes, and arranging subsequent verification.

There is an undeniable gap between visual representations and actual writing materials. Digital pen research shows that changes in tools affect children's writing experience and output quality, meaning feedback design must account for medium characteristics (Mann et al., 2015). Gerth et al. (2016) compared the writing of preschoolers, second-graders, and adults on tablets versus paper, finding that the lower surface friction of tablets altered writing speed across all groups, and that children's output quality was lower in tablet conditions for certain tasks. The interaction of resistance, elasticity, and ink diffusion formed by the brush, Xuan paper, and ink is far more complex. Screen or sensor recordings can only explain some phenomena in paper-based practice and cannot replace on-site observation of the brush tip's condition and the material's response.

The scale of the CalliSense study illustrates the types of judgments that existing evidence can support. Its formative phase interviewed 8 participants; a subsequent short-term workshop evaluation included 4 teachers and 12 learners (Gong et al., 2025). The evaluation used a within-participant comparison of CalliSense-assisted and traditional teaching. Its questionnaires and interviews primarily examined self-reported understanding of brush techniques and classroom experience, rather than independently measured writing performance. The questionnaire and interview findings indicate that process recording can provide materials for joint observation and feedback dialogue between teachers

and students; however, whether students have truly learned to adjust their brushwork must still be confirmed by subsequent brush-and-paper writing, as well as retention and transfer performance.

Translating Visual Representations into Motor Competence

Motor knowledge in brush copying is deeply embedded in specific materials and writing contexts, making it difficult to reduce to a set of universally applicable parameters. Completing a horizontal stroke involves the initial point of contact, the spreading of the brush tip, the resistance encountered during execution, the coordination between the wrist and arm, the transition between pressing and lifting, and the control applied at the conclusion. The writer must continuously make micro-adjustments based on real-time feedback from the paper. While pressure curves can indicate changes in the measured force variable, they cannot replace the tactile sensations generated by the coordination of fingers, wrist, and arm. Similarly, while trajectories can reveal positional deviations, determining whether the brush tip remains stable still requires integrating tactile feel with the traces left on the paper. Screen-based information can only participate in actual brushwork regulation after it has been interpreted, tested through movement attempts, and calibrated against physical sensations.

Difficulties in translating visual information into motor competence do not all occur at the same stage. Some students can see the fluctuations in a curve but fail to understand its relationship with the spreading and gathering of the brush tip; for these students, teachers must first clarify the meaning of the representation. Others directly interpret the synchronous changes in pressure and line thickness as a causal relationship, ignoring factors such as speed, ink volume, and paper resistance; in such cases, multiple pieces of evidence should be compared to avoid hastily attributing causality based solely on correlation. Still other students can accurately verbalize that they need to reduce pressure, yet their wrist and arm movements remain unchanged once they hold the brush. When verbal judgments have not yet translated into motor control, simply adding more visual explanations may be insufficient; teachers can also use demonstrations, movement breakdowns, and continuous feedback from the materials. Applying a uniform prompt to these diverse difficulties risks misdiagnosing a processing issue as a mere lack of information.

Students' understanding of process information must ultimately return to brush-and-paper activities beyond the screen. A relatively complete learning task should simultaneously cross-reference process markers, traces on the paper, physical sensations during writing, and plans for the next movement. Teachers can ask students to point out where a line changes, describe the force or brush tip state at that specific moment, and explain the adjustments they intend to make. Such explanations form a testable motor hypothesis, which the subsequent copying attempt is responsible for confirming or refining. Repeated brush-and-paper checks can help determine whether an improvement persists without interface support or remains a short-term response to a specific curve or prompt.

Medium differences also affect learning transfer. Tablets and paper differ significantly in terms of tactile feedback, friction, and visual feedback, a discrepancy that is particularly pronounced for beginners (Gerth et al., 2016). If

the primary training occurs on a digital surface, learners may gradually adapt to the kinematic requirements of the device itself without developing the control strategies applicable to a brush and Xuan paper. Even if the device serves only as a data acquisition tool, the persistent presence of an interface may alter the student's original attentional structure, causing their gaze to linger excessively on screen metrics. Digital recording must maintain a stable back-and-forth relationship with brush-and-paper practice; any improvement observed on an interface must be validated under real writing conditions.

Specific studies reveal significant contextual variations. Danna et al. (2015) had 32 adults learn unfamiliar characters with their non-dominant hand; real-time auditory feedback improved short-term speed and fluency but reduced short-term spatial accuracy, and some of these differences were not maintained in a 24-hour retention test. Research on mixed reality calligraphy tasks showed that additional visual feedback and participant experience jointly influenced cognitive load and motor performance (Loup-Escande et al., 2017). A pilot study on sensor-based writing training involved only 10 doctoral students in educational technology, with the task being Devanagari characters; presenting all feedback simultaneously increased mental effort, and the study did not measure writing learning outcomes (Limbu et al., 2019). A 12-week tablet writing study covering 22 kindergarten classes, which examined Latin alphabet writing, found that additional benefits in the paper-and-pen post-test appeared only in children with intermediate initial skill levels (Bonneton-Botté et al., 2020). A pilot study closer to Chinese character learning, AI-Strokes, included 50 second-grade students from a primary school in Singapore (28 in the experimental group and 22 in the control group) across four sessions spanning 1.5 months. The experimental group showed superior pre-to-post test changes across three types of error metrics; specific means and between-group tests are presented in Table 1 (Wong et al., 2023). This pilot used an early tablet-based hard-pen prototype, with both pre- and post-tests conducted within the system, and did not include delayed testing or transfer to brush-and-paper writing. Collectively, existing research highlights the importance of feedback load, foundational learning levels, and retention tests, while also illustrating the risks of generalizing inferences across different tools and writing systems.

Table 1. Comparison of Pre- and Post-Tests Between the Experimental and Control Groups in the AI-Strokes Pilot Study

Indicator	Experimental Group M (SD) Pre-test → Post-test	Control Group M (SD) Pre-test → Post-test	Between-group Test
Stroke order errors	77.43 (4.23) →70.93 (4.94)	73.86 (3.91) →75.77 (3.89)	F=11.447 p=.001
Extra or missing strokes	3.96 (2.43) →1.96 (2.73)	5.55 (3.14) →5.86 (1.71)	F=28.587 p<.001

Indicator	Experimental Group M (SD) Pre-test → Post-test	Control Group M (SD) Pre-test → Post-test	Between-group Test
Stroke direction errors	1.75 (1.84) →0.89 (1.69)	2.14 (2.05) →1.55 (1.54)	F=8.812 p=.005

Note: The three indicators represent the number of errors, with lower values indicating better performance. Wong et al. (2023) used parametric analysis of covariance (ANCOVA) for stroke-order errors and Quade's nonparametric ANCOVA for extra or missing strokes and stroke-direction errors, with pre-test scores as covariates. Data adapted from Wong et al.

Existing evidence can illustrate how process visualization enters the classroom, but it does not justify treating the mere recording of a movement, the explanation of a difficulty, a temporary improvement in performance, and the stable formation of competence as the same outcome. Once motor discrepancies enter the classroom, it is necessary to examine how students interpret these discrepancies, whether the interpretation triggers corresponding motor adjustments, and whether the learning can be maintained and transferred once the prompts are removed. Technical metrics belong to process recording; cross-material verification forms diagnostic evidence; corresponding changes in subsequent writing constitute evidence of regulation; and stable learning requires retention and transfer. Confusing these levels risks mistaking system sensitivity, a single plausible explanation, or a short-term score for true educational effectiveness.

DISCUSSION

Conditions for Feedback Intervention

There are no fixed rules regarding feedback frequency and presentation timing that apply universally to all motor tasks. A meta-analysis by McKay et al. (2022), encompassing 61 studies and 2,228 participants, found no stable advantage in reducing feedback frequency for motor learning or performance. Nor did it support the predicted reversal in the relative effects of high- and reduced-frequency feedback between practice and delayed retention. Complex tasks or the initial stages of learning may require more frequent prompts, whereas continuous display in other scenarios may foster dependency, disrupt rhythm, or divert attention. Calligraphy classrooms cannot deduce the frequency of feedback directly from abstract rules; rather, adjustments must be made based on the nature of the task, student performance, and changes observed after prompts are removed.

Research on children's motor learning has similarly failed to establish a stable hierarchy for feedback. Van der Veer et al. (2022), reviewing 13 studies on children's functional gross motor skills, found that evidence for reducing feedback frequency was largely conflicting or insufficient. While learner-controlled feedback timing showed some advantage for retention, the overall quality of the research was low, and the tasks differed significantly from fine motor writing. Another meta-analysis of 18 studies suggested that self-controlled feedback may

benefit motor learning (Jimenez-Diaz et al., 2021). These findings support gradually expanding student choice in the classroom, but they do not imply that beginners should independently decide what to observe and when from the very beginning. When students are not yet able to identify key discrepancies, the focus of observation can be restricted by the teacher; once basic judgment capabilities are developed, students can then decide whether to review and which types of evidence to utilize.

Feedback design should originate from the current writing task. When identifying the direction of stroke initiation or comparing turning positions, slow-motion playback, local overlays, and trajectory markers can provide clear references. However, when maintaining the coherent rhythm of a sequence of strokes, the complete movement and tactile sensation on the paper are more important than local parameters. The student's existing experience informs the level of detail to which information can be refined. Teachers can start beginners with a small number of direct, immediately actionable prompts and introduce comparisons across several variables as learners become able to interpret them. Presentation channels and timing must align with attentional allocation, ensuring that necessary information appears at stages where it can be interpreted without hindering the current movement. Multimedia learning research indicates that additional representations irrelevant to the goal or poorly organized will consume limited cognitive resources (Mayer, 2021).

Feedback content must also distinguish between writing outcomes and their potential causes. A contour that is too wide is an outcome that has already occurred; excessive pressure, changes in speed, or a failure to gather the brush tip are merely candidate causes. While system recordings can provide relevant clues, causal judgments still require synthesizing teacher demonstrations, on-site observations, student self-reports, and traces on the paper. Teachers should select the evidence that best explains the current difficulty and translate that judgment into an actionable requirement for the next attempt. Whether a prompt is arranged before, during, or after the movement also depends on its actual impact on attention and rhythm; a prompt that aids preparatory movements may not be suitable for continuous display during continuous writing.

Taking the lifting and pressing rhythm of horizontal strokes in regular script for upper primary grades as an example, a teacher might first propose a problem identifiable on the paper, have students watch a complete demonstration, and then use a slow-motion side view to verify key positions. During the students' initial copying attempt, the teacher provides brief prompts or none at all, depending on their foundational skills, while retaining a concise process record. After writing, the teacher and student retrieve only one piece of evidence directly related to the current problem, linking the screen information, the lines on the paper, and the physical sensations of the movement. During the subsequent copying attempt, scaffolding is reduced, and the student implements a specific adjustment; similar strokes or new characters are then used to test whether this adjustment can be transferred. This arrangement confines feedback to specific problems while preserving the necessary space for unassisted verification.

The ability to interpret process information varies across different educational stages, and this discrepancy should be treated as a variable in classroom research. During the initial stages of primary school, students primarily face challenges in stabilizing their grip, basic stroke direction, and material resistance; complex curves may exceed their interpretive capabilities, making brief demonstrations and single-movement prompts more appropriate. Once upper primary students have developed a degree of control, they can compare stroke rhythm and turning positions. Middle school students, when copying complete characters or different steles and rubbings, can further discuss why multiple valid treatments exist for similar strokes, avoiding the misconception of expert samples as the sole set of parameters. These judgments are derived from task complexity, medium research, and feedback evidence, but they still require validation through cross-stage classroom comparisons. Furthermore, improvements in local strokes should be examined within the context of stroke connections, structural arrangement, and the copying of new characters.

Failed performance in the classroom can help teachers identify where learning stagnation occurs. If a student can point out a pressure issue but the lines on the paper remain unchanged, verbal judgment may not yet have translated into motor control. The initial diagnosis and other movement variables also need checking; in this case, it is advisable to shorten the movement unit, reduce speed requirements, or provide additional demonstrations. If a student only improves when prompts are continuously displayed, it suggests that external support may be fostering dependency; prompts should be gradually reduced, and retention tests should be arranged. If system prompts contradict teacher observations, the model, acquisition conditions, equipment errors, and paper results must be verified. Technology adds diagnostic clues, not automated solutions; pedagogical handling still depends on professional judgment regarding the causes of difficulties.

To determine whether digital feedback is appropriate, one must first examine whether the task complexity and student experience can support the understanding of the information; the quantity of information, sensory channels, and timing of intervention affect how attention is allocated, while unassisted practice is responsible for verifying whether the prompts have truly been integrated into motor actions. Necessary prompts that do not disrupt rhythm can be retained during continuous writing, whereas if the interface occupies attention, feedback should be deferred until after the movement. Regardless of the approach adopted, students' paper-based results and their performance after support is removed must be included in the evaluation. The number of features a device possesses does not determine its place in the classroom; features constitute meaningful pedagogical intervention only when they correspond to specific learning problems and are validated by subsequent writing.

Process Evidence, Assessment, and Transfer

This study proposes an analytical distinction among process recording, diagnostic evidence, regulatory evidence, and learning evidence, with the criteria for determination presented in Table 2. These four levels do not represent merely renaming the same batch of data layer by layer: trajectories, pressure, and video

address how the movement occurred; diagnosis requires that process segments, traces on the paper, on-site observations, and student sensations jointly support a plausible causal explanation; regulatory evidence links a proposed motor adjustment to corresponding changes in subsequent writing; and learning evidence further examines retention and transfer after scaffolding is removed. Each level requires evidence appropriate to its claim. The levels do not prescribe a fixed sequence that every learner must follow, and the framework has not been validated as a model of learning stages.

Table 2. Judgment Levels and Minimum Requirements for the Process Evidence Chain

Evidence Level	Required Materials and Key Tests	Supported Claims	Cannot Be Inferred From This Alone
Process Recording	Trajectories, pressure, speed, brush posture, video, or system logs; verification of equipment calibration, time synchronization, writing materials, and recording completeness.	When, where, and in what measurable manner a specific movement changed.	The cause of the change, whether the pedagogical diagnosis is correct, or whether the student has learned.
Diagnostic Evidence	Cross-referencing process segments with traces on the paper, on-site teacher observations, and the student's physical sensations of the movement, alongside comparing alternative explanations.	A specific motor discrepancy is a plausible cause of the current writing difficulty.	The student can execute the corresponding adjustment, or that the cause is universally applicable.
Regulatory Evidence	A specific motor adjustment is identified; prompts are reduced during subsequent writing, and it is observed whether the expected motor and paper-based changes occur simultaneously.	The diagnosis has been translated into an observable motor adjustment.	The adjustment can be maintained without scaffolding, retained long-term, or transferred to other tasks.

Evidence Level	Required Materials and Key Tests	Supported Claims	Cannot Be Inferred From This Alone
Learning Evidence	Unassisted brush-and-paper tests, retention tests after a predetermined interval, and transfer tasks involving similar strokes or new characters.	Motor regulation can be independently maintained and applied in related tasks.	The tool has an overall effect across all students, script styles, and learning stages.

Note: The levels indicate the scope of claims that the evidence can support, rather than device precision or evaluation scores. Claims at subsequent levels require additional evidence appropriate to the claim and cannot be automatically established from the preceding level.

Taking the lifting and pressing of a horizontal stroke as an example, a decrease in recorded finger-to-handle pressure indicates a change in the measured grip variable, not necessarily a change in brush-tip contact with the paper. Before using the paper result to assess the diagnosis, the teacher must check whether the intended brush movement occurred. If it did not, the attempt cannot test the proposed explanation. If it did but the expected line change is absent, the diagnosis remains unconfirmed; the extent of the adjustment, speed, ink volume, and brush-tip state also need checking. Improvement in the lines while screen prompts are continuously displayed shows better performance under feedback but does not by itself establish independent motor regulation; only when similar horizontal strokes are completed after the prompts are removed can it be determined whether the regulation can be independently maintained. Furthermore, evidence points to retention and transfer only if the adjustment can still be made after a predetermined time interval and in new characters that involve similar brushwork. At each level, results may fail to support the claim being tested. Before deciding what to revise, teachers need to identify whether the failure concerns the causal explanation, execution of the adjustment, or testing conditions.

Placing school-based calligraphy evidence within this chain makes the current research gaps clearer. Huang and Qiao (2024) organized online peer assessment involving 136 fifth-grade students from three primary schools in Beijing. Following training on assessment criteria, student ratings were positively correlated with teacher ratings across most indicators, and 81.6% of the students expressed satisfaction with the scores they received. This study primarily focused on completed works without recording the grip, stroke order, or the brushwork process; the authors also listed full-segment writing videos and process analysis as directions for future research. These findings support the participation of the fifth-grade students in this study in product-based calligraphy assessment after training. The study shows how learners can use shared criteria to judge finished works; it does not establish how process information contributes to interpreting or adjusting brush movements.

Table 3. Process Evidence and Applicability Boundaries of Representative Studies

Study & Context	Process Information or Feedback	Primary Outcome Evidence	Scope and Boundaries of Supported Claims
CalliSense (Gong et al., 2025) Formative interviews with 8 participants; workshop evaluation with 4 teachers and 12 learners; brush calligraphy.	Video, inertial, and pressure sensors recorded brush posture, finger pressure on the brush handle, and rhythm, supporting post-session review and joint discussion.	A within-participant comparison using questionnaires and interviews indicated higher self-reported understanding of brush techniques and more positive classroom experience under CalliSense-assisted teaching than under traditional teaching.	Directly involves the brush process and includes a traditional-teaching comparison; short-term self-report findings do not establish independent writing performance, delayed retention, or transfer.
Danna et al. (2015) 32 adults; single-session training; immediate and 24-hour post-tests; unfamiliar characters.	Writing with the non-dominant hand; movement speed and fluency were converted into real-time auditory feedback.	Short-term speed and fluency improved, while spatial accuracy temporarily declined; some differences were not maintained at 24 hours.	Supports the differentiation of feedback effects across various metrics; subjects were adults, and it does not involve brush writing or school classrooms.
Limbu et al. (2019) 10 doctoral students in educational technology; short-term trial; Devanagari script.	A sensor-based trainer presented multimodal feedback, including visual and auditory cues, simultaneously.	The full-feedback condition increased mental effort; the study did not measure writing learning outcomes.	Supports judgments regarding information load, but cannot serve as evidence of improved writing competence in children.
Bonneton-Botté et al. (2020) 22 kindergarten classes; 12 weeks; Latin alphabet.	A tablet app analyzed form, stroke sequence, and direction, providing feedback after each trial; paper-and-pen pre- and post-tests were used.	Additional benefits from digital training appeared only in children with intermediate initial writing levels.	Features a longer duration and paper-and-pen tests, but differs from brush copying in terms of the writing system and tools.

Study & Context	Process Information or Feedback	Primary Outcome Evidence	Scope and Boundaries of Supported Claims
Wong et al. (2023) 50 second-grade students in Singapore (28 experimental, 22 control); 4 sessions over 1.5 months.	A tablet recorded the hard-pen writing process of Chinese characters, providing feedback on stroke order, extra/missing strokes, and stroke direction; pre- and post-tests were conducted within the system.	Pre-to-post test changes across three types of error metrics were superior to the control group; specific data are presented in Table 1.	Provides process and outcome data in a children's school context, but lacks delayed testing, paper-and-pen transfer, or brush tasks.
Huang & Qiao (2024) 136 fifth-grade students from 3 primary schools in Beijing; 4 brush calligraphy assessment tasks.	Students conducted anonymous online peer assessments based on 10 criteria across three categories: structure, strokes, and writing.	Student ratings were positively correlated with teacher ratings across most indicators; 81.6% of students were satisfied with their scores.	Closest to the primary and secondary school brush context, but the assessment targeted finished products without recording the writing process, motor adjustments, or retention.

Note: Sample sizes, durations, tasks, and outcomes are compiled based on the original studies. "Evidence boundaries" represent judgments on the scope of applicability derived from the research design. Due to significant heterogeneity among the studies, effect sizes are not pooled in this table.

None of the six studies compared in Table 3 reports the full set of evidence linking process recording, diagnosis, motor adjustment, and brush-and-paper transfer in primary and secondary school students. Within this comparison, studies involving brush or calligraphy training rely on adult samples, short-term workshops, or product-based evaluations. The process-oriented studies provide evidence about recording, interpreting, or discussing writing, but offer limited evidence of unassisted retention and transfer. Conversely, studies with larger samples and longer durations involving children primarily utilize tablet-based hard-pen writing or Latin alphabets. Therefore, while the judgment that process visualization aids in problem location and feedback organization is supported by research, the claim that it can stably form brush copying competence in primary and secondary school students still lacks a closed loop of evidence—spanning process recording, diagnosis, motor regulation, and brush-and-paper transfer—within a single research design.

Learning outcomes must ultimately be confirmed through brush-and-paper tasks with minimal external support. Immediate score increases or improvements on the same model only indicate performance during the practice phase. More

comprehensive learning evidence also includes writing after prompts are removed, retention after a time interval, and adjustments when facing new characters or similar strokes. Students' explanations and proposed corrections can help make their judgments visible. Independent improvement maintained in retention and transfer tasks provides stronger evidence of learning; a verbal explanation alone is insufficient, and learners need not verbalize every aspect of motor control. Transfer tests should also use brushes and similar paper to avoid mistaking proficiency in device operation for brush copying competence.

CONCLUSIONS AND RECOMMENDATIONS

Digital process visualization preserves the fleeting and implicit movements in brush copying, adding materials to classroom observation and diagnosis that were previously difficult to recall repeatedly. Its educational role arises not from the act of recording itself, but from the process in which teachers and students interpret evidence around specific problems, propose motor adjustments, and return to brush-and-paper verification. If process information does not correspond to specific difficulties or fails to elicit testable subsequent writing, it will ultimately remain at the level of mere viewing, scoring, and technological demonstration.

Feedback arrangement is a set of decisions that vary with instructional conditions. Task objectives define the objects of observation, student experience informs the level of detail to which information can be refined, presentation channels and timing regulate attentional load, and brush-and-paper practice is responsible for verifying whether external prompts have been integrated into motor actions. Beginners in lower primary grades, upper primary students, and middle school students who need to compare script differences should not be subjected to the same feedback intensity and assessment thresholds. Teachers bear the responsibility for evidence selection, causal judgment, and pedagogical handling. Algorithms are primarily used for recording and comparison, and are simultaneously constrained by material differences, aesthetic openness, and data governance requirements

FURTHER STUDY

The research reviewed here is insufficient to estimate the overall effectiveness of various process visualization tools in primary and secondary school brush copying. Relevant evidence spans adults and children, brush and hard-pen writing, Chinese characters and other writing systems, and direct classroom studies are limited in sample size and duration. Future research should report the educational stage, script style, task difficulty, feedback content and frequency, mode of device intervention, and brush-and-paper transfer outcomes within authentic school contexts, and must include unassisted and delayed tests. Only by forming comparable classroom evidence can we verify the mechanisms of process visualization, stage-specific differences, and the assessment chain, thereby establishing a relatively stable pedagogical basis for the selection of digital tools.

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