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Article

Digital technology integration innovation and visual symbol design of Huizhou ink painting skills under bioengineering

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Abstract: In response to the problems of insufficient interactive experience and unstable inheritance caused by information loss and deformation in the teaching process of Huizhou ink painting skills, this article explores a new method to protect and inherit Huizhou ink painting skills through the integration of biotechnology and digital technology. At the same time, a modern visual symbol design is developed to revitalize this ancient art form in contemporary society and promote its dissemination and exchange worldwide. Firstly, traditional Huizhou ink painting materials were analyzed using biotechnology to understand their composition, structure, and aging mechanism. Scientific and effective protective measures were proposed, and a database was constructed by collecting and matching images of each step in the process. Then use 3D modeling to model the manufacturing tools. By extracting visual elements from micro ink artwork images, drawing basic graphics, and completing visual symbol design. Finally, integrate Unity and Vuforia Engine to design an interactive experience module for Weizhou ink painting production skills, creating an immersive digital interactive environment. In the improved micro ink production process experience display experiment, compared with the existing graphic and textual display methods, the audience's satisfaction and innovation scores for the digital integration method were 19.1% and 21.6% higher, respectively. The conclusion indicates that bioengineering analysis can accurately identify and delay the aging process of ink painting materials, while digital technology has successfully achieved high-quality digital reconstruction of classic works.

Keywords: Huizhou ink making skill; bioengineering technology; visual symbol design; digital technology; integrated innovation

1. Introduction

Huizhou ink is a unique ink technique. As a part of traditional Chinese culture, it has rich historical and cultural connotations [1,2]. Originated in the Tang Dynasty, it is one of the four treasures of Chinese traditional study. It is refined with Mount Huangshan pine smoke and animal glue as the main raw materials. It has a long history and enjoys a high reputation. With the progress of the times, Huizhou ink making skills are in a severe stage of development. The traditional production process of Huizhou ink is complex, the production environment is difficult to control, and it is difficult to resist the damage caused by natural environment to the works, such as material aging caused by factors such as light and humidity. It mainly relies on word of mouth from master to apprentice, and lacks systematic records and protection methods, resulting in instability in the craftsmanship. This not only restricts the healthy development of the Huizhou ink industry, but also causes many precious cultural relics to be lost and forgotten. Using modern technology to realize the innovative inheritance of Huizhou ink making skills and enhance its competitiveness in the market is an important path

to achieve the sustainable development of Huizhou ink culture. With the support of biotechnology, traditional ink making techniques in Huizhou have been innovated. By applying microbial fermentation technology, the processing of ink raw materials can be optimized, improving the quality and environmental friendliness of ink. With the continuous improvement of information technology, digital technology is also developing rapidly [3]. Through in-depth analysis of the manufacturing process of Huimo using biotechnology, we aim to understand its composition, structure, and mechanism, and develop scientifically effective protective measures. At the same time, utilizing digital technology to record and digitally preserve the entire production process of Huizhou ink, and finding new ways to achieve sustainable development of traditional culture. It is of great value and significance to improve the efficiency and effectiveness of the inheritance of Huizhou ink culture, and promote the popularization of Huizhou ink culture.

As a valuable asset of China's intangible cultural heritage, the value and inheritance of Huizhou ink making skills are of great significance to Chinese civilization [4,5]. With the improvement of awareness of traditional cultural protection, certain progress has been made in the research on the inheritance of Huizhou ink craftsmanship. Liu [6] believed that the inheritance of Huizhou ink craftsmanship is currently facing problems and challenges, such as a shortage of inheritors, difficulty in cultivating talents, and stagnation in craftsmanship innovation. To solve the dilemma of Huizhou ink inheritance, it is necessary to raise awareness, strengthen top-level design, deeply explore cultural connotations, and popularize intangible cultural heritage education [6]. Huang [7] considered that "productivity" is an important attribute and characteristic of traditional handicraft intangible cultural heritage, and its production method is closely related to the inheritance of craftsmanship. Only by regarding Huizhou ink culture, production, circulation, and sales as a dynamic system, and maintaining dynamic evaluation and implementing targeted regulation from the macro perspective of cultural ecology, can the dynamic, complete and high-quality inheritance of Huizhou ink making skills be promoted [7]. Current research mostly explores the topic from aspects such as historical background, cultural value and inheritance status. However, facing the challenges and development difficulties of the modern market, how to achieve the stable inheritance of traditional craftsmanship remains an important issue in current research.

Bioengineering not only has strong technological innovation capabilities, but its achievements can directly improve the quality of human life, protect the environment, and bring economic benefits to society [8,9]. In the field of cultural heritage protection, the application of biotechnology is opening a new chapter. As traditional conservation methods become increasingly difficult to cope with the complex challenges of preserving cultural relics, scholars have begun to explore cutting-edge technologies such as biomaterial analysis, microbial control, and bioremediation to delay the aging and damage of artworks. Materials such as biopolymers [10] and nanocellulose [11] provide valuable insights into the prospects of sustainable and innovative solutions due to their unique mechanical and physical properties. Gomez Villalba Luz Stella explores the role of nanotechnology in the preservation of architectural, artistic, archaeological, or museum heritage, analyzing current treatment methods using nanomaterials, including retarders, fungicides, hydrophobic protectants, mechanical

resistance improvers, flame retardants, and multifunctional nanocomposites, in repairing and preventing weathering, pollution, or biological effects [12]. David Madalina Elena explores the application of tubular nanomaterials in the protection of cultural heritage in response to the threat of continuous degradation of cultural relics and historic sites, and introduces their excellent mechanical, elastic strength, and relatively good biocompatibility [13]. These studies have enhanced our understanding of the materials used in historical artifacts and provided a solid scientific foundation for the long-term preservation of global cultural heritage. However, there are still limitations in the development of specific sustainable conservation strategies.

The development of digital technology has provided more possibilities for the production and inheritance of current traditional crafts [14,15]. To study the inheritance of digital intangible cultural heritage, Zhang [16] expounded on the digital protection of intangible handicrafts and analyzed the process and design methods of establishing a digital protection platform. The use of digital means to realize the expression form and cultural space of digital intangible cultural heritage handicrafts provides effective support for the inheritance and development of intangible cultural traditional handicrafts [16]. In order to effectively improve the dissemination of the intangible cultural heritage craftsmanship of architectural painting, Chen [17] proposed developing digital models of architectural painting and focusing on scientific dissemination, transforming architectural painting into digital models so that more audiences can understand Chinese traditional culture through modern scientific and technological means [17]. Based on the application of digital technology, by designing visual symbols that have both cultural connotations and a sense of the times, not only can the brand image of traditional technology be enhanced, but also the public's awareness and participation can be increased, thereby promoting the wider and longer-term preservation of craftsmanship [18–20]. Taking the Chinese West Lake Longjing tea culture as an example, to better understand the social significance of traditional Chinese visual language in contemporary tea packaging, Hu [21] combined the theory of visual social semiotics and visual design, and provided a basis for enriching the expression of traditional cultural symbols by understanding the symbols used in packaging. To further strengthen the intrinsic relationship between visual information and cultural heritage protection, Xu and Yang [22] took the digital restoration of Southern Dynasty stone carvings as the research object and conducted research on the innovative design of digital visual information. Combining visual elements such as images, symbols, and scenes with modern digital technology, the form and culture of cultural relics can be better protected and inherited [22]. In the digital translation of regional cultural symbols in the icon design project, Wei [23] took the concept of visual codes as the basis and analyzed the narrator's creative methods and motivations from the connotation rules contained in the icons and the formal rules used in the development, providing a new way of interpreting regional cultural heritage. These studies provide new perspectives and methodologies for the modernization of traditional craftsmanship, but still face challenges in issues such as audience participation and experience.

To achieve the stable preservation and development of Huizhou ink making skills and improve the audience's sense of participation and experience, this paper studies the integration of Huizhou ink making skills and digital technology. Through the

collection of pictures of process steps, 3D modeling of making tools, extraction of visual symbols, and design of interactive experience, the innovative inheritance and visual symbol design of Huizhou ink making skills are realized. To verify its effectiveness, an evaluation is conducted on four levels: audience participation, cultural dissemination effect, visual symbol design feedback, and audience experience. In terms of audience participation, compared with graphic and text display, the average number of audience interactions increases by 1.0 times, and the average interaction duration increases by 1.2 minutes. In terms of cultural dissemination effect, the mean results of the method in this paper in the three evaluation dimensions of cultural influence, audience interest and dissemination willingness are 27.5%, 23.9% and 27.3% higher than those of the graphic and text display method respectively. In the visual symbol design feedback, the final mean scores of the aesthetics and understanding of the method in this paper are 15.2% and 7.5% higher, respectively. In terms of audience experience, the average satisfaction and innovation scores are 19.1% and 21.6% higher respectively. With the integration of digital technology, the audience can effectively participate in the understanding and learning experience of the making skills, and have a deeper understanding of its visual symbols, which can help promote the innovative inheritance of Huizhou ink making skills.

2. Integration of Huizhou ink making skills and digitalization

2.1. Improvement of Huizhou ink making skills

In the production of Huizhou ink, from raw materials to formulas and then to the addition of auxiliary materials, each step has its own characteristics, and there is no unified standard. This is also different from the records in ink manuals of past dynasties [24]. However, from ancient times to modern times, the general ink-making process can be divided into four important steps: material preparation and processing, mixing and molding, drying and curing, and packaging and binding.

(1) Material preparation and processing

To make Huizhou ink, the materials should be prepared and processed first. In material preparation, high-quality pine wood should be selected as raw material to ensure that the soot generated after its combustion is of high purity and high quality. The pine wood is sent to a special furnace and then burned at a certain temperature and time to produce soot. During combustion, the flame needs to be strictly controlled to ensure the quality of the soot. When the soot cools, a filter is used to remove large particles and impurities to make the soot finer and more uniform. Animal glue (such as cowhide glue) is then dissolved in warm water. To improve the quality of Huizhou ink, appropriate essence and other additives, such as musk, can be added to the ink to adjust the viscosity and aroma of Huizhou ink.

(2) Mixing and molding

After material preparation and processing is completed, it is the process of mixing and molding. The processed soot and glue are mixed in the prescribed proportion using a blender or manually until there are no particles at all. The prepared soot glue is poured into the prepared wooden or metal mold and pressed hard until the surface is flat.

(3) Drying and curing

During the drying and curing process, the mold containing the soot glue is placed in a ventilated and dry place to allow it to dry naturally, and the ink block is checked regularly to ensure that the ink block is dried uniformly. When the ink block is completely dry, it is removed from the mold, and pre-grinding is started. The surface of the ink block is polished with sandpaper or grinding stone to achieve a smooth effect.

(4) Packaging and binding

After drying and curing, final packaging and binding are carried out. Sandpaper or a grinding stone is used to carefully polish it to ensure it is smooth without defects. After polishing, the ink stick should be engraved to facilitate identification and tracking. Finally, the ground ink block should be wrapped in paper and protected from moisture.

In the production process, the instability of raw material quality is a major problem. As the core component of Huizhou ink, the quality of pine soot has an important impact on the performance and application of ink. However, in conventional combustion processes, it is often difficult to ensure the uniformity of soot collection and combustion temperature, resulting in differences in the fineness, purity and color of the obtained pine soot. Due to the instability of raw materials, the quality of Huizhou ink produced in different batches may be uneven and cannot meet the modern market's requirements for stability and high quality.

With the continuous advancement of biological and material sciences, micro-biological degradation technology and nanotechnology are becoming increasingly mature [25–27]. Combining biotechnology and nanotechnology and optimizing the process during the preparation can improve the quality and stability of the product. In the specific production process, micro-biological degradation technology is adopted to improve the purity of raw materials. The raw materials are modified by biological enzymes to enhance the properties of the glue. Microbial metabolites are used to optimize the mixing and molding processes, and nanomaterials are used to optimize the drying and curing processes, as shown in **Figure 1**.

In **Figure 1**, a nanomaterial dispersion is prepared before pine wood incineration. Nano-silicon dioxide and nano-alumina are added to deionized water in a ratio of 1:5, and ultrasonic dispersion technology is used to ensure the uniform distribution of nanoparticles in the liquid phase, thereby improving its stability. When the pine wood is burned, it is first treated using microbiological methods. The wood with white rot fungi is used to decompose microorganisms, and the pine wood is fermented in a controlled environment. On this basis, through reasonable ventilation methods, it is placed in an environment with air circulation at 25–30 ℃ to increase its degradation rate and promote the production of aromatic compounds. After two weeks of fermentation, the combustion operation is carried out. Appropriate firepower is used, and the supply of oxygen and temperature are controlled to make the formation of pine soot more uniform and prevent the soot quality from being reduced due to the increase in temperature.

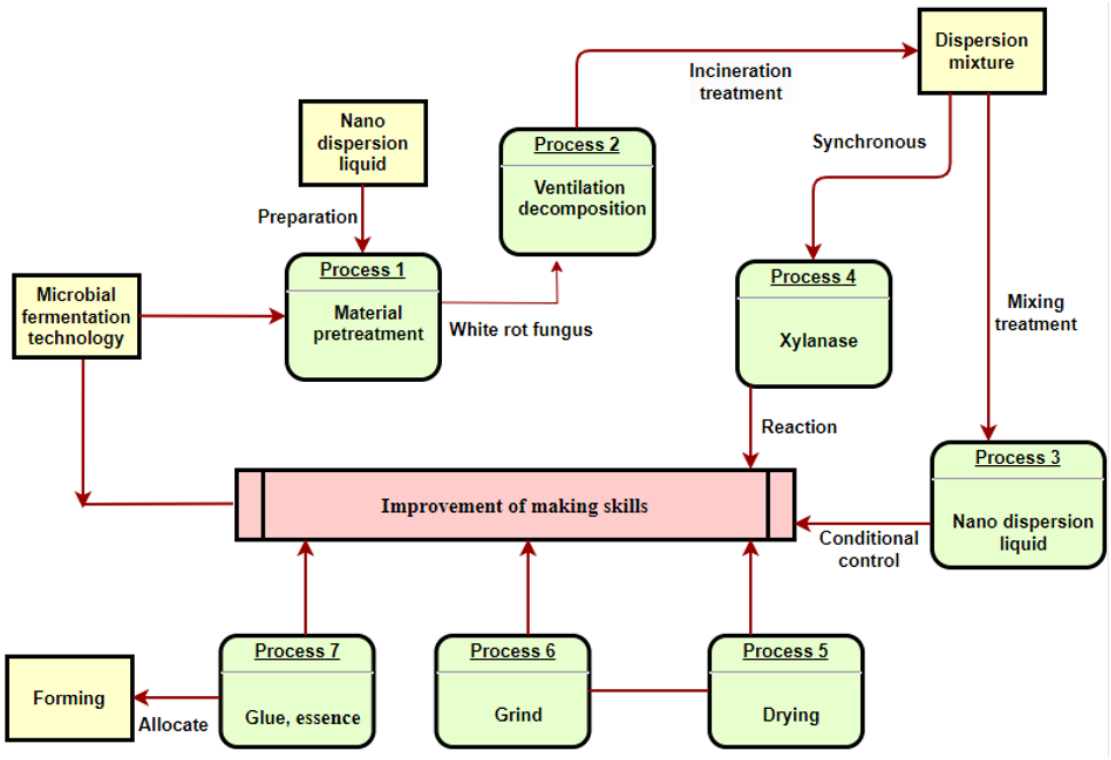

Figure 1. Improvements in Huizhou ink making skills.

After the incineration is completed, the obtained soot powder is mixed with the pre-prepared nano-dispersion solution, and 10ml of the dispersion solution is added to every 100 g of soot powder. Then, it is stirred to ensure that the nanomaterials can fully adhere to the soot. After comprehensive improvement, xylanase is added to modify the soot, so that the structure of the soot can be further decomposed. The enzyme concentration is adjusted, and the reaction is allowed to proceed for 3 hours. The treated soot is placed in a vacuum drying oven and dried under vacuum at 60 ℃ for 4–6 hours to remove excess moisture and promote chemical bonding between the nanomaterial and the soot. After drying, the mixture is ground. Finally the ground soot is mixed with appropriate glues and essences to create the finished product. The comparison between traditional methods and improved methods is shown in **Table 1**:

Table 1. Comparison between traditional and improved methods.

Process stage	Traditional method	Improved method
Raw material processing	Burning pine wood to collect cigarette ash results in significant quality fluctuations.	Microorganisms degrade pine resin to improve the purity and fineness of pine smoke.
Gel preparation	Animal glue is simple to boil and has a single property.	Enzyme modified animal glue enhances viscosity and compatibility.
Mixed molding	Hand mixed, relying on experience.	Microbial metabolites assist in improving mixing uniformity and molding quality.
Drying and solidification	Natural drying takes a long time and is prone to deformation.	Nanomaterials promote rapid drying and maintain shape stability.

Under bioengineering, white rot fungi and other humic microorganisms are used for pretreatment of pine trees. This bacterium can secrete a large amount of extracellular enzymes, such as cellulase, hemicellulase, and catalase, which can

efficiently degrade wood fibers, improve raw material purity, and promote the production of aromatic substances. On this basis, xylanase is used to modify cigarette smoke, enabling it to better decompose complex organic compounds and improve its physical properties. This enzymatic reaction can make cigarette ash particles finer and more uniform, and enhance their adhesion with glue and other additives. Accurately controlling the concentration of enzymes and reaction time during this process is an important factor determining the efficiency of modification. By dispersing nano silica and nano alumina in a certain proportion in deionized water solution, a stable suspension is prepared for drying and curing processes. Under the action of ultrasound, nanoparticles are uniformly dispersed in the matrix, improving the surface properties and durability of the product. Finally, the cigarette ash is uniformly mixed with the nano dispersed solution, and vacuum low-speed drying technology is used to achieve close contact and chemical bonding between the cigarette ash and the nano dispersed solution, constructing stronger and more durable composite materials. Throughout the entire production process, the stirring rate, grinding force, and vacuum drying conditions have a direct impact on the quality of each process. Proper agitation can ensure sufficient adhesion of nanoparticles to cigarette ash; Fine grinding can make the final product particle size meet the requirements, resulting in smooth writing and more ideal color presentation.

2.2. Application design of digital technology

In the context of digitalization, the instability of oral transmission in traditional craft production is also a major problem affecting the inheritance of intangible cultural heritage [28,29]. In order to better demonstrate the Huizhou ink craftsmanship under bioengineering, improve the lack of interactivity and unstable inheritance, this article combines digital technology to construct a digital model of Huizhou ink production techniques, digitally record and manage the production process, and achieve innovative inheritance and visual symbol design. Its overall framework is shown in **Figure 2**:

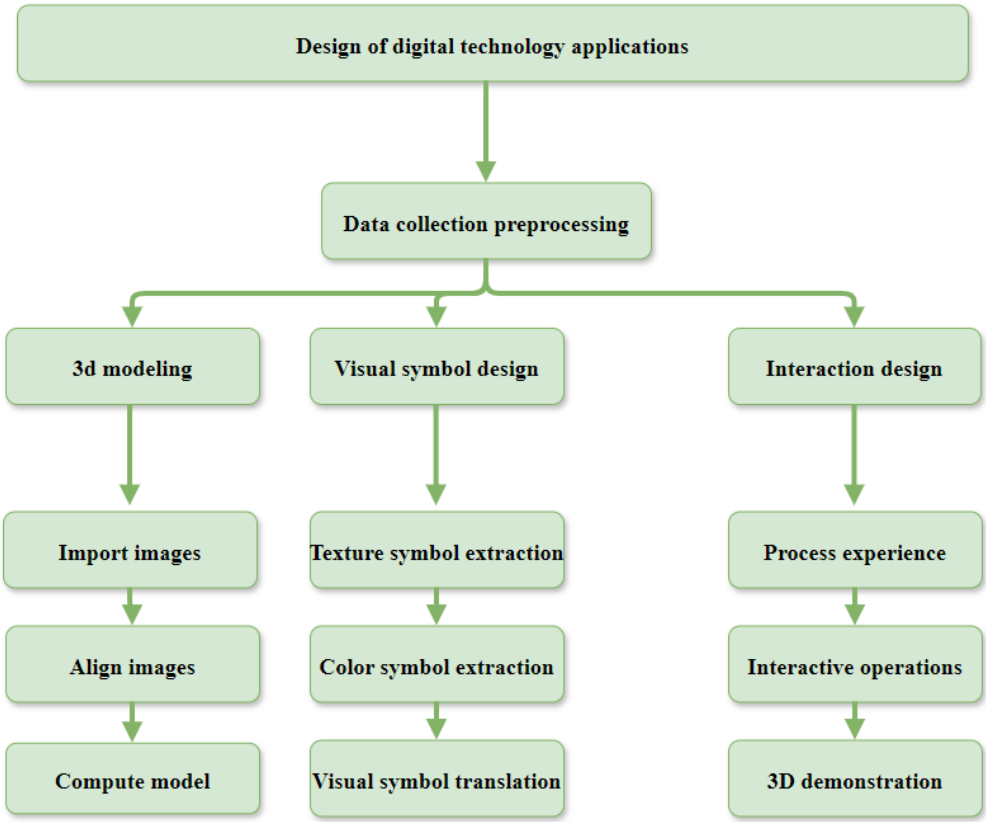

Figure 2. Framework of the digital model of Huizhou ink making skills.

2.2.1. Data collection and organization

First, relevant historical materials, including ancient books, craft manuals, historical materials, etc., are collected from collections and archives to understand the relevant historical background to ensure the accuracy and completeness of the craft process. The actual pictures of the Huizhou ink making process are obtained from relevant websites, and each step is recorded. Then the collected information is categorized. According to the content of the data, the making process is matched with the actual pictures, as shown in **Figure 3**. For each piece of information, the paper verified it from multiple independent sources such as different historical documents and relevant academic research, and invited experts and scholars in the field to review the collected data to ensure its authenticity and reliability.

Based on the data collection and organization in **Figure 3**, the most distinctive tools and equipment in Huizhou ink making process are summarized as follows: screen meshes, wooden molds, ventilation racks, grinding tools, carving tools, and templates. The shapes of the tools are analyzed by combining data and pictures, as shown in **Figure 4**.

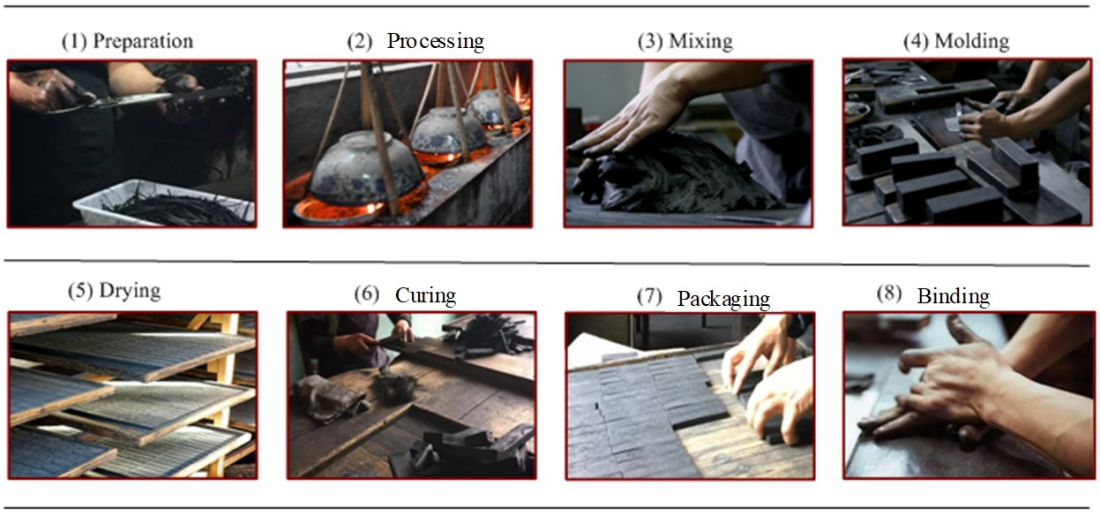

Figure 3. Data collection and organization.

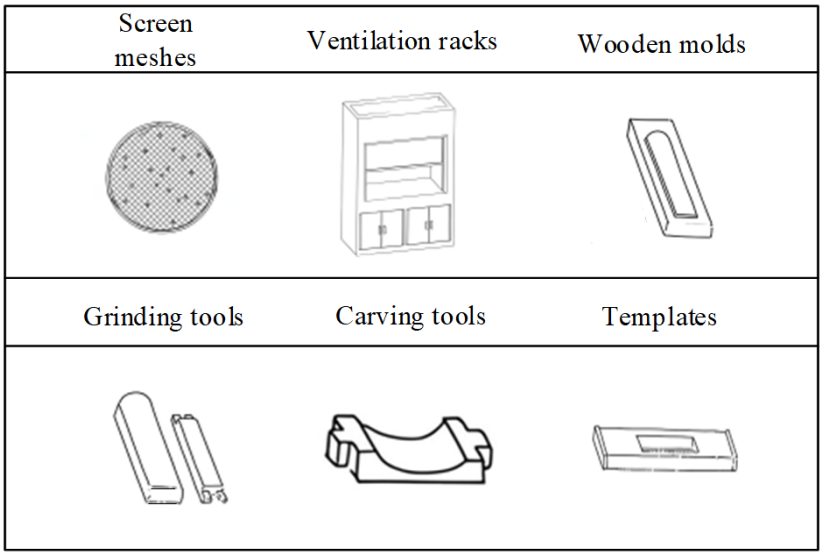

Figure 4. Tools' line drawings.

In **Figure 4**, the sizes of each tool are measured, and the parameter information is input into Photoshop. The line drawings are vectorized and demechanized to ensure their original appearance is intact. They are then integrated and saved to form a database as a basis for subsequent modeling and visual design.

2.2.2. Three-dimensional modeling

The 3D modeling technology is used to digitally collect the tools used in Huizhou ink making skills, and the scanned 3D models are stored and input into the modeling software for optimization. The tools manufactured by Huimo have complex shapes and fine structures, and require high precision for 3D scanning. Low scanning accuracy can easily cause model distortion and cannot accurately reflect the details of the tool. For this purpose, this article selected a high-precision 3D scanner and preprocessed the tool before scanning, thereby improving the resolution and accuracy of the scan. During this process, multiple scans of the same object are performed to obtain a more complete model. To address the issue of images containing a large amount of noise and redundant information, the Blender algorithm is used to remove

noise and smooth surfaces. For some complex parts, segmented scanning and splicing methods were adopted to ensure accurate processing of each part.

(1) Importing pictures

The pre-collected pictures are input into the 3D modeling platform AutodeskMeshmixer [30]. A new project is created in the program, and the "import" is selected. Then the pictures are imported one by one. When importing, the resolution and format of each picture are unified. Photoshop is used for pre-processing to adjust brightness, contrast and color balance.

(2) Aligning pictures

After the pictures are imported, all the pictures are aligned, and each key point where there is a picture is marked. Before marking, it should be ensured that the same feature points in the pictures have the same positions in different pictures. After all key points are marked, they are aligned according to their position information. During this process, the positions of various key points are constantly adjusted. By rotating, scaling, translating, and other operations on the pictures, they can be completely matched in three-dimensional space [31].

(3) Computing model

Before computing the model, its set values should be properly adjusted first and calibrated to determine the reconstruction range. Then the redundant parts should be excluded from the reconstruction area, thereby shortening the modeling time [32,33]. After the reconstruction settings are completed, the model is computed by generating model quality. The fundamental matrix is estimated using the RANSAC (Random Sample Consensus) method [34]:

$$x'Fx = 0 \tag{1}$$

In Equation (1), x and x' represent the coordinates of the points corresponding to the two pictures, and their essential matrix E is:

$$E = T^T K^T F K \tag{2}$$

In Equation (2), T is the translation vector, and K is the intrinsic parameter matrix.

On this basis, the PnP (Perspective-n-Point) problem is solved by using the existing feature points and the extrinsic parameters of the basic matrix [35–37].

The three-dimensional coordinates of feature points are reconstructed using multi-view geometry [38,39]. Finally, the model is output and stored. The model is exported in OBJ format. The models are classified in detail, divided according to tool type and purpose, so that each model can be clearly identified and described.

2.2.3. Visual symbol design

Visual symbols can simplify complex information into an easily understandable form [40]. By extracting the visual symbol elements from the pictures of works with Huizhou ink and drawing basic graphics, the visual symbol design is completed. The design steps are divided into three parts: texture symbol extraction, color symbol extraction and visual symbol translation:

(1) Texture symbol extraction

There are many kinds of texture symbols in Huizhou ink, and the common natural

types include flower patterns, bird patterns, animal patterns, and sun, moon, and star patterns, etc. From the perspective of visual expression of texture symbols, the texture patterns in Huizhou ink are mostly drawn using linear techniques. Firstly, through the collection of a large amount of literature, a preliminary screening of Huizhou ink paintings was conducted, and a representative batch of Huizhou ink patterns were selected from them. On this basis, a detailed analysis of the image was conducted using PS software, and the main pattern elements were determined. Taking Huimo's landscape paintings as an example, there is a special spiral pattern on them, which has both aesthetic value and profound cultural significance. It can be separated from the background to make it a separate base graphic. To make the method more intuitive, this article also designed a diagram, as shown in **Figure 5**, which illustrates the process from the original graphics to pattern extraction. The left is the basic pattern of the spiral pattern, and the right is the extracted specific symbol.

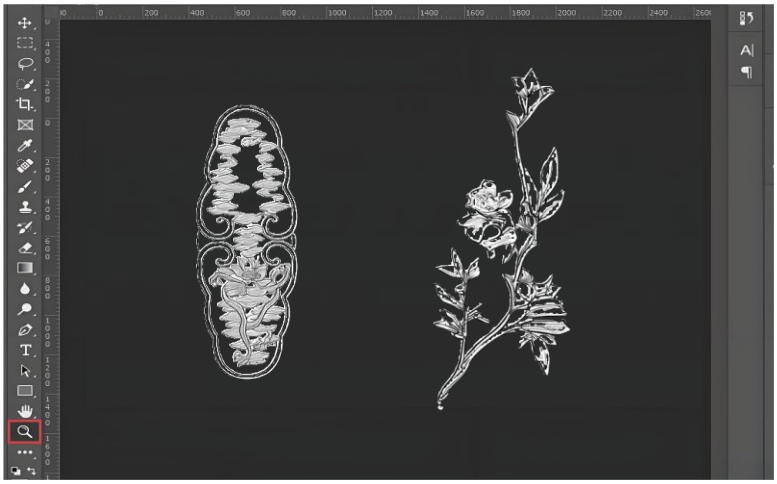

Figure 5. Flower pattern symbol extraction.

In **Figure 5**, first, the flower pattern elements used in Huizhou ink making are collected, and these texture samples are digitized using 3D scanning technology. On this basis, the acquired texture picture is preprocessed. Photoshop is used to remove the cluttered background. Then the "curve adjustment" tool is used to adjust the brightness and contrast, and the "sharpen" tool is used to enhance the details of the material. Then the texture is separated from the background, and the texture features are extracted. Finally, the extracted texture features are sorted, and the corresponding texture symbol library is established, labeled and classified.

(2) Color symbol extraction

Huizhou ink is mainly composed of plain colors, and the black and white alternating painting technique is mostly used in the processing of the picture. The visual morphemes of black and white contrasts are often used to distinguish each other. In the extraction of color symbols, representative color samples used in the production of Huizhou ink are selected, including the color of the Huizhou ink itself, the color of the mold, etc. The color samples are digitized by scanning. The acquired color pictures are preprocessed, and the colors are corrected and enhanced using Photoshop, as shown in **Figure 6**. The "levels" tool is selected, and the "color balance" tool is used to adjust the brightness and contrast of the picture. Then the picture is segmented and

the color features are extracted and analyzed. The distribution of each channel on the RGB histogram is statistically analyzed, the color components are described. The extracted color features are organized into a color symbol library.

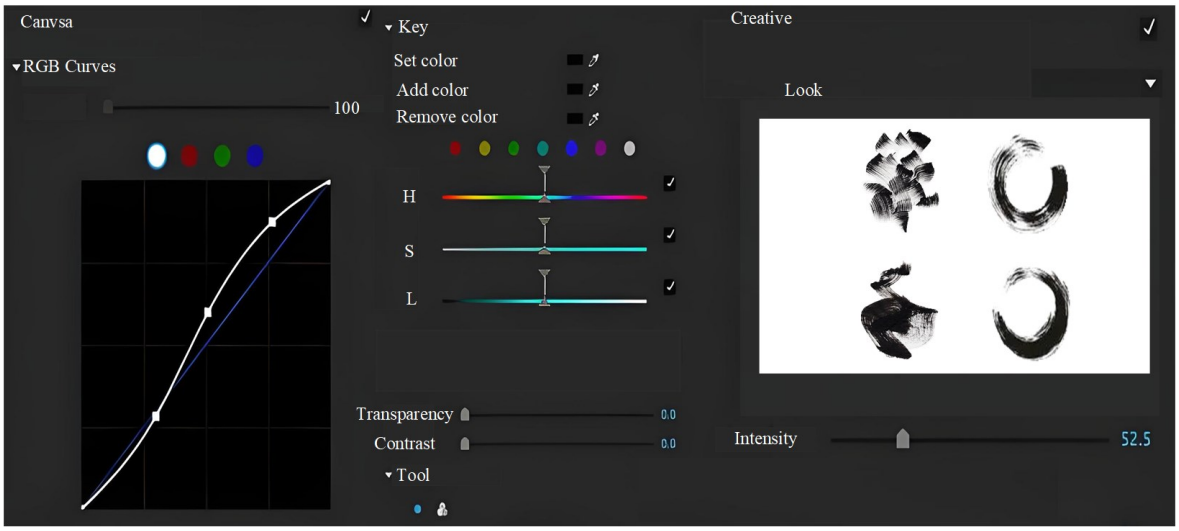

Figure 6. Color symbol extraction.

(3) Visual symbol translation

In the process of translating the visual symbols of Huizhou ink, representative visual symbols are extracted based on the making skills, textures and colors, such as the particle shape in soot extraction, the uneven surface of the mold, the gloss effect, etc., and presented in the design in a visual way. Colors and patterns are extracted to explore themes, and patterns are deconstructed and reorganized, integrating to build a visual symbol system.

2.2.4. Interaction design

The core of Huizhou ink making skills is the presentation of the craft process. To achieve innovative inheritance, an interactive experience module is designed. By creating an immersive digital interactive environment, the audience can experience the scene and atmosphere of Huizhou ink making. With the help of visual symbol elements that enhance participation, the audience can have an intuitive understanding of the entire production process and implementation process. The making skill process of Huizhou ink includes material preparation and processing, mixing and molding, drying and curing, packaging and binding. Based on 3D modeling and visual symbol design, interactive experience design is carried out according to the requirements of operation content.

At the beginning of interaction design, this article collected users' needs and expectations through questionnaires and interviews, to understand their preferences and usage habits towards Huizhou ink production technology. A realistic and lifelike interactive system prototype can be created for target users to test. At the same time, based on the actual operation of users, the article collected relevant feedback to evaluate the practicality and ease of use of interactive design, as well as to evaluate the user's investment and satisfaction with the interactive experience module. Among these indicators, participation and satisfaction are noteworthy. After collecting user

feedback, quantitative and qualitative analysis was conducted on the data. On this basis, the interaction design can be optimized to ensure that the final interaction experience module can better meet the needs of users and enhance their sense of participation and satisfaction. The paper provided a simple user manual to guide users on how to conduct interactive experiences. Users can quickly grasp the operation methods of interactive experience through the combination of videos and graphics. A step-by-step explanation can be designed to allow users to complete each step of the ink making process step by step. Each step has detailed explanations and usage methods, and users can follow the guide for practical operations.

At the same time, combining traditional Chinese instruments such as guzheng and flute, the paper provided tourists with a good cultural environment. Equipped with professional textual explanations, the paper introduced each process of Huizhou ink and the cultural allusions it contains. The content of the audio includes historical background, production technology, cultural symbols, etc., which helps users to have a relatively complete understanding of the production techniques of Huizhou ink, and provides a detailed textual description of it. It also introduces its historical origins, development context, and cultural background. The content covers the anecdotes of ancient literati and the customs of using ink during traditional festivals, enhancing the cultural identity of users.

First, a new project is created in Unity and then integrated with Vuforia Engine [41–43]. Then the 3D model is input into Unity, and the texture symbol library and color symbol library are imported. The model is colored according to the material. The solution elements are configured to meet needs of Vuforia. Models are added to the scene, and their position, scale, and rotation parameters are set. The tools provided by Vuforia are used to complete object recognition and tracking.

In 3D modeling and visual symbol design, the use of 3D models and visual symbol systems can better reproduce the manufacturing process of Huizhou ink, but the lack of dynamic interaction restricts people's profound understanding of the Huizhou ink manufacturing process. To this end, this article introduces real-time simulation function, allowing users to observe and adjust the production steps in real time through interactive means, and enhance their dynamic understanding of the ink making process. At the same time, adding tactile feedback function allows users to feel changes in various materials and tools during use, enhancing immersion. Embedding dynamic interactive elements in a 3D model allows users to interact with the model by clicking, dragging, and other means to obtain more information. In the virtual reality world, users can observe and manipulate various devices and materials from various angles, and have a sense of immersion. On this basis, the paper established a user feedback mechanism to provide reference for subsequent improvements based on feedback and suggestions after the experience is over.

The designed interface, icons, animations, and other materials are input into the Unity software, and corresponding operations are set according to the design of the interaction content. The animation is set by adding components, and the animation play is set by coordinate points. Then the applying is clicked, and the design of the process experience is completed. In interactive mode, the process experience is interactive through operations such as clicking and sliding. The icon buttons in the scene are used to extract elements and simulate the Huizhou ink making process

according to the process content and entity images. After clicking on the process experience, the start screen of the skill process is entered, and starting experience can be clicked on to get more content. The entire interaction process is completed by clicking a button on the toolbar.

3. Evaluation of the effect of integration of Huizhou ink making skills and digital technology

3.1. Experimental preparation

To verify the integration effect of Huizhou ink making skills and digital technology, this article takes an online Huizhou ink making skills-related theme experience project as the object and takes the Huizhou ink making skills process improved by biotechnology and nanotechnology as an example. Through the digital model of Huizhou ink making skills, the process of the skills is summarized and its dynamic effects are drawn to realize the experience display of the interactive process, and it is compared with the graphic and text display method. According to the making skill process, the application scenarios are divided into 8. Taking material preparation as an example, in the application scenario, two methods are used to demonstrate the collection process of Huizhou ink raw materials, such as pine soot, etc.

To improve the representativeness and applicability of the research, this article further expanded the sample size during the experimental preparation stage, including audiences from different backgrounds and environments, and explored multiple themes in Huizhou ink painting or related crafts. In the sample selection, participants from different age groups (young people (18–35 years old), middle-aged people (36–60 years old), and elderly people (over 60 years old), as well as from different educational backgrounds (audiences from middle school to higher education), were invited to classify their familiarity with Huizhou ink into beginners (completely unfamiliar with and preliminary understanding of Huizhou ink making techniques), enthusiasts (with certain knowledge and practical experience), and professionals (with in-depth research or work experience in the field). The samples include audiences from physical museums, craft studios, cultural events, and online platforms to ensure that the experiences of audiences in different environments are fully reflected. In the research, multiple themes related to Huizhou ink painting and related crafts will be explored, including the history, production techniques, and cultural significance of Huizhou ink, to enrich the research content and improve its applicability.

The audience participating in the theme experience is selected as the sample object. Before the evaluation, the audience is informed of the purpose and significance of the survey, and is led to experience the Huizhou ink making skill process using the combination of graphic and text and the digital integration method. The integration effect of Huizhou ink making skills and digital technology is objectively evaluated from four aspects: audience participation, cultural dissemination effect, visual symbol design feedback, and audience experience. The audience participation is compared through online recording. Relying solely on online records cannot fully reflect the audience's true participation and interactive experience. Therefore, this article also collects qualitative data through interviews and focus groups. After the experiment,

in-depth interviews were conducted with some participants to understand their specific feelings and problems encountered during the interaction process. And the other three levels are compared through questionnaire analysis. The questionnaire composition is shown in **Table 2**:

Table 2. Questionnaire composition.

Classification	Serial number	Dimension
Basic information	1	Gender
	2	Age
	3	Educational level
	4	Cognitive level of Huizhou ink making skills
Cultural dissemination effect	1	Cultural influence
	2	Level of interest
	3	Willingness to disseminate
Visual symbol design feedback	1	Aesthetic level
	2	Understanding level
Audience experience	1	Satisfaction
	2	Innovation

In **Table 2**, the evaluation of the dimensions of cultural dissemination effect, visual symbol design feedback, and audience experience adopts the Likert five-level scale, as shown in **Table 3**:

Table 3. Question item rating and value assignment.

Level	Classification	Score (point)
1	Very disagree	1
2	Disagree	2
3	General	3
4	Agree	4
5	Very agree	5

In **Table 3**, the answers to the questions are divided into five levels and assigned scores of 1–5.

3.2. Experimental results

3.2.1. Sample descriptive analysis

A total of 532 audiences participate in this online theme experience. 532 questionnaires are distributed, and 460 valid questionnaires are collected. The sample information is shown in **Table 4**:

Table 4. Sample information.

Dimension	Classification	Number of people	Proportion (%)
Gender	Male	235	51.1
	Female	225	48.9
Age	18–35	203	44.1
	36–60	161	35.0
	Over 60	96	20.9
Educational level	Junior high school and below	56	12.2
	Senior high school or vocational high school	104	22.6
	Junior college or undergraduate	212	46.1
	Postgraduate and above	88	19.1
Cognitive level of Huizhou ink making skills	Completely not understanding	147	32.0
	Preliminary understanding	173	37.6
	Basic understanding	109	23.7
	Deep understanding	31	6.7

From **Table 4**, it can be found that the gender distribution of the sample objects in this survey is relatively balanced, with males accounting for 51.1% and females accounting for 48.9%. In terms of age distribution, samples in the age group of 18 to 35 years old account for 44.1%. The large proportion of young groups may be related to the form of online survey in this article. In the dimension of educational level, samples with junior college degree or bachelor's degree account for the largest proportion, reaching 46.1%, which means that most of the sample objects have a good level of education. In the classification of the degree of knowledge of Huizhou ink, there are more sample groups who have no knowledge of Huizhou ink making skills and those who have a preliminary understanding of it, with the proportion reaching 32.0% and 37.6% respectively. This means that among the sample group surveyed, most people do not have a high level of knowledge about Huizhou ink and its making skills.

3.2.2. Audience participation

The degree of participation directly reflects the audience's level of interaction with the graphic and text display and the digital integration of the Huizhou ink making skills. In the audience participation evaluation, the average number of interactions and average interaction duration of the audience in different scenarios with each method are recorded to compare the two methods. The results are shown in **Figure 7**.

Figure 7 shows the comparison of audience participation of different methods. Judging from the number of interactions in **Figure 7a**, in each application scenario, the average number of interactions of the audience of digital integration in this article is about 3.2 times, and the average number of interactions of the audience of graphic and text display is about 2.2 times. Judging from the interaction duration in **Figure 7b**, with the display method that combines Huizhou ink making with digital technology, the average interaction duration of the audience in each application scenario is about 5.8 minutes, while the average interaction duration in each scenario using the traditional graphic and text display method is about 4.6 minutes. The digital

integration in this article provides a more intuitive and convenient way for the audience to understand and learn relevant knowledge about making skills through a more dynamic and interactive experience. Compared with the graphic and text display, the average number of audience interactions increases by 1.0 times, and the average interaction duration increases by 1.2 minutes.

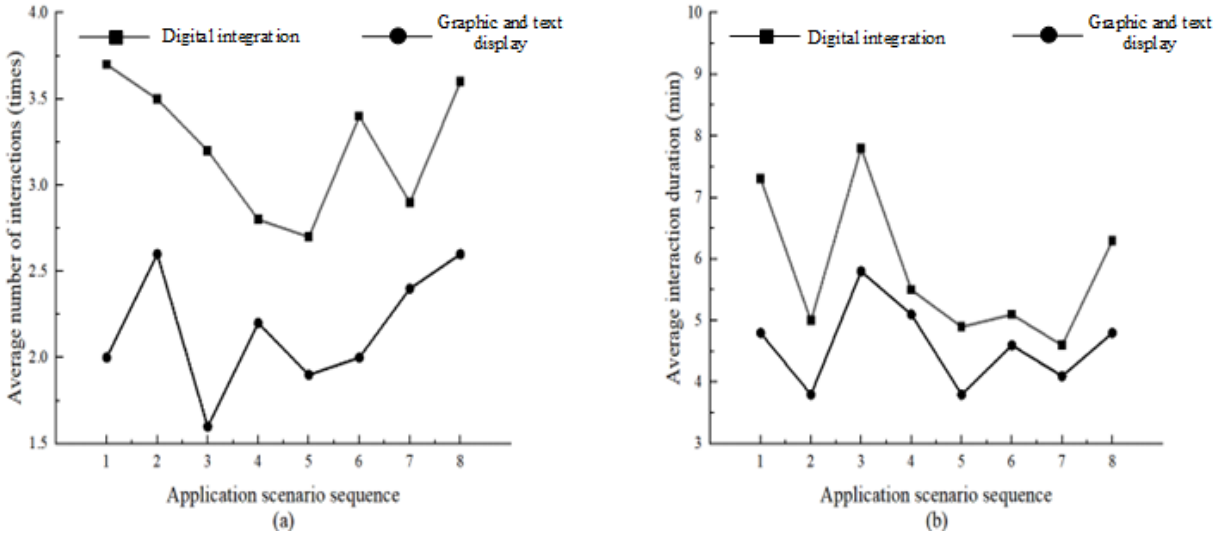

Figure 7. Comparison of audience participation. **(a)** The average number of interactions; **(b)** The average interaction duration.

3.2.3. Cultural dissemination effect

The cultural dissemination effect reflects the effectiveness of digital technology in disseminating and promoting Huizhou ink making skills. The comparison is made through the mean score results of the cultural influence, level of interest, and willingness to disseminate in the questionnaire survey. The comparison of cultural dissemination effects with the graphic and text display method and the digital integration method in this article is shown in **Figure 8**:

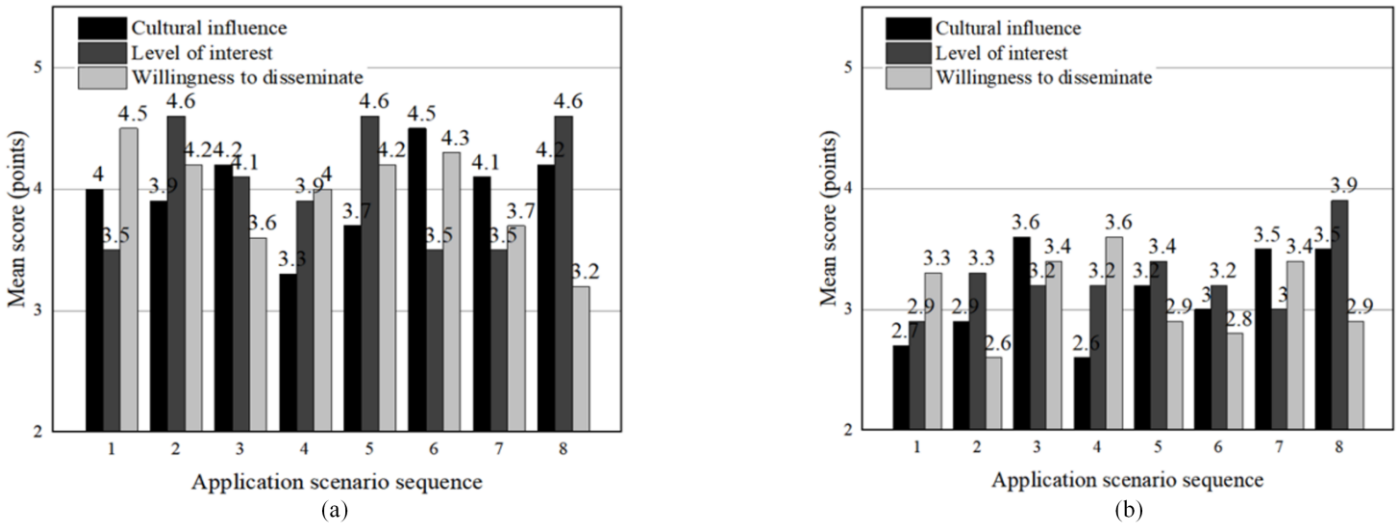

Figure 8. Comparison of cultural dissemination effects. **(a)** The results of the digital integration method; **(b)** The results of the graphic and text display method

Judging from the comparison of cultural dissemination effects in **Figure 8**, the survey scores of cultural influences, audience interest level, and dissemination willingness of the method in this article are generally higher than those of the graphic and text display method. In **Figure 8a**, the mean scores of the digital integration method in the display of Huizhou ink making skills in terms of cultural influence, audience interest, and willingness to disseminate are approximately 3.99, 4.04, and 3.96, respectively. In **Figure 8b**, the mean results of the graphic and text display method in the three evaluation dimensions are 3.13 points, 3.26 points, and 3.11 points respectively. In the result comparison, the average results of the method in this article in the three evaluation dimensions are 27.5%, 23.9% and 27.3% higher than those of the graphic and text display method respectively. The results show that by combining with digital technology, Huizhou ink making skills can have a higher influence and can attract more audiences and enhance the audience's willingness to actively disseminate. Compared with static graphic and text displays, the method in this article provides audience with a dynamic interactive experience, which is conducive to conveying important details and information in Huizhou ink making and improving its display effect.

To comprehensively evaluate these effects, the paper compared the digital transformation of Huizhou ink making techniques with the digital transformation of similar traditional crafts or cultural heritage. It selected Xuan article production, ceramic production, and traditional Su embroidery techniques that have also undergone digital transformation, and analyzed their performance in cultural dissemination, as shown in **Table 5** [44–46].

Table 5. Comparison of traditional craft culture communication.

Classification	Huimo production techniques	Xuan paper production	Ceramic manufacturing	Suzhou embroidery
Cultural influence	3.99	3.85	3.74	3.82
Level of interest	4.04	4.01	3.95	4.02
Willingness to spread	3.96	3.93	3.66	3.85

Based on the comparison results in **Table 5**, digital technology in this article has a significant effect on enhancing the cultural influence, interest level, and dissemination willingness of traditional Huizhou ink crafts, but the performance varies among different crafts. These differences may be related to the characteristics of the process itself, the cognitive foundation of the audience, and the application of digital technology.

3.2.4. Visual symbol design feedback

In each application scenario, visual symbols are displayed using the graphic and text display and digital integration methods. Visual symbols related to Huizhou ink making are displayed, and detailed symbol information is provided. Taking the aesthetics and understanding as indicators, the audience's visual symbol design feedback of different methods is compared, as shown in **Figure 9**:

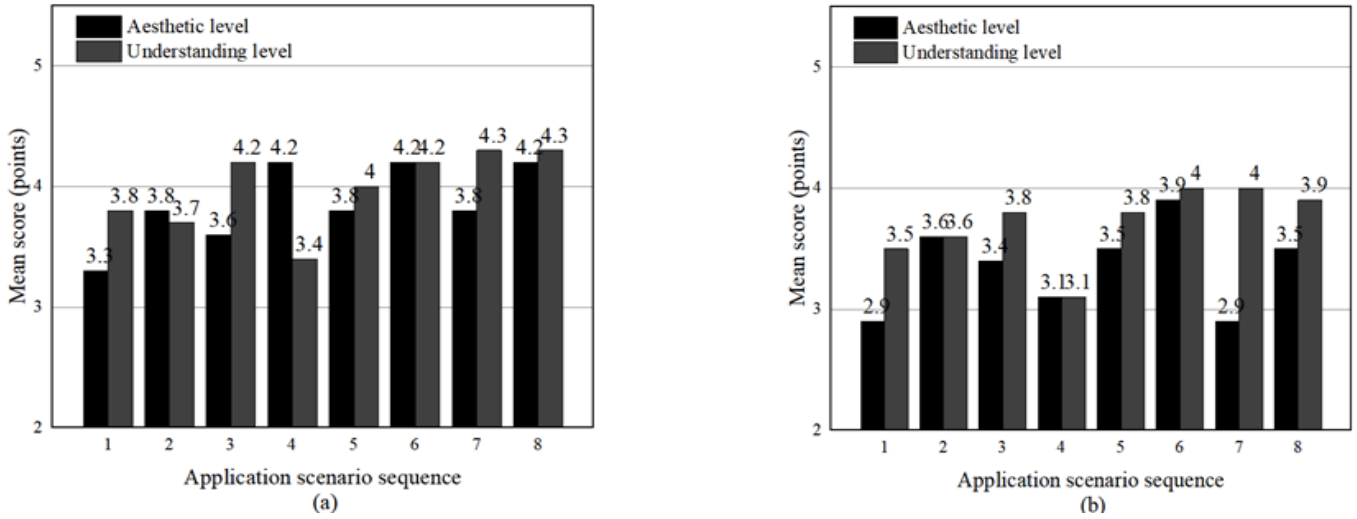

Figure 9. Comparison of visual symbol design feedback. **(a)** The results of the digital integration method; **(b)** The results of the graphic and text display method.

Judging from the feedback results in **Figure 9**, the visual symbol design of this article has more significant advantages in terms of aesthetics and understanding. In **Figure 9a**, the mean aesthetic level score in the visual symbol design feedback of the digital integration is 3.86 points, and the mean understanding level score is 3.99 points. In **Figure 9b**, the mean aesthetic level score in the visual symbol design feedback of the graphic and text display is 3.35 points, and the mean understanding level score is 3.71 points. In comparison, the final mean scores of the aesthetics and understanding of the method in this article are 15.2% and 7.5% higher, respectively. By extracting the representative texture and color of Huizhou ink during the making process and performing mapping processing, the visual symbol design that integrates Huizhou ink making skills with digital technology not only has good aesthetic value, but also can effectively convey key making skill information, helping the audience understand the culture and inheritance of the skills.

Although the overall evaluation is high, there are still shortcomings in the design of visual logos. Some viewers have provided feedback that the details of some visual symbols are not handled properly, resulting in a slight decrease in aesthetic appeal. In addition, some symbols have certain difficulties in conveying complex technical information. In response to the above shortcomings, it is necessary to strengthen the handling of details, especially the conversion of texture and color, to ensure that each logo has a high artistic quality. And more textual explanations and illustrations, especially for more complex technical steps can be added, which require more detailed annotations to assist the audience in understanding and grasping the key points.

3.2.5. Audience experience

The audience experience reflects the audience's evaluation of the satisfaction and innovation of the theme display methods after watching the theme displays of different methods. The comparison results are shown in **Figure 10**:

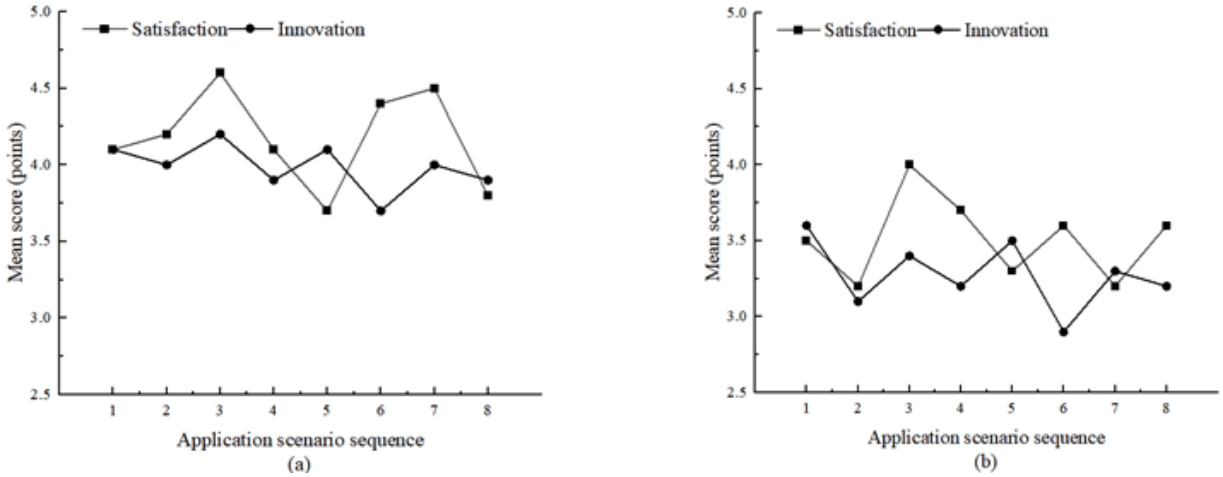

Figure 10. Comparison of audience experience. **(a)** The results of the digital integration method; **(b)** The result of the graphic and text display method.

From the audience experience comparison in **Figure 10**, it can be seen that the audience satisfaction and innovation evaluation results are higher with the method in this article. In **Figure 10a**, the average satisfaction score of the method in this article is about 4.18 points, and the average innovation score is about 3.99 points. In **Figure 10b**, the average satisfaction score of the graphic and text display method is about 3.51 points, and the average innovation score is about 3.28 points. Judging from the specific comparison results, the audience's satisfaction and innovation perceptions of the digital integration method are significantly higher than those of the graphic and text display method, with the average satisfaction and innovation score results being 19.1% and 21.6% higher respectively. Digital integration provides a more intuitive and immersive space for the display of Huizhou ink making skills. Its new display and interactive forms provide a richer medium for the inheritance of Huizhou ink culture. It not only effectively improves the audience's satisfaction with the theme experience, but also enhances their perception of the innovation of the display method.

To comprehensively evaluate the long-term impact of digital integration methods on audience experience and knowledge retention, it is recommended to conduct a longitudinal study on the sample participating in this experiment. The research period is one year, divided into four stages, each lasting three months. At the end of each stage, data will be collected through questionnaire surveys and interviews to evaluate participants' satisfaction and innovative perception of the theme presentation method. The results are shown in **Table 6**:

Table 6. Longitudinal analysis of audience experience.

Classification	The digital integration method		The graphic and text display method	
	Satisfaction evaluation	Innovation evaluation	Satisfaction evaluation	Innovation evaluation
Phase 1	4.18	3.99	3.51	3.28
Phase 2	4.22	4.01	3.60	3.32
Phase 3	4.26	4.06	3.58	3.35
Phase 4	4.39	4.15	3.58	3.37

Table 6 shows that the digital fusion method has the most significant effect on improving audience satisfaction and innovative cognition. By comparison, the satisfaction index of graphic and textual display has shown a downward trend, while the innovation score has increased slightly, but the increase is not significant. This result indicates that the digital fusion method can not only bring users a better user experience in a short period of time, but also continuously improve user satisfaction and innovation in the long run.

4. Conclusion

As an intangible cultural heritage, Huizhou ink making skills face the problems of inheritance and sustainable development in modern society. With the help of biotechnology, Huizhou ink making not only retains the soul of traditional craftsmanship, but also achieves a dual improvement in efficiency and environmental protection. The application of enzymatic technology accelerates the conversion of raw materials such as pine smoke and tung oil, reduces the production of harmful substances, and makes the production process more green and healthy. To stably record and preserve the essence of Huizhou ink making skills and realize its innovative inheritance, this article studies the innovative inheritance and visual symbol design of Huizhou ink making skills with the integration of digital technology. By collecting pictures of the making skill process to build a database, and performing 3D modeling of the tools, representative textures and colors of Huizhou ink are extracted, and a visual symbol library is constructed to achieve digital preservation of making skills and visual symbol design. In terms of user participation, compared with the graphic and text display, the average number of audience interactions of digital integration increases by 1.0 times, and the average interaction duration increases by 1.2 minutes. In the comparison of cultural dissemination effects and visual symbol design feedback, the score results of the method in this article are generally higher than those of the graphic and text display method. From the audience experience survey, the mean results of scores for satisfaction and innovation of the method in this article are 19.1% and 21.6% higher respectively.

This article combines digital technology with Huizhou ink making skills to effectively enhance audience participation and experience, improve the cultural dissemination and visual symbol design effects of Huizhou ink making skills, and has a certain driving effect on its innovative inheritance. In addition to Huimo technology, this article can also provide reference for the protection and inheritance of other traditional technologies. Traditional techniques such as “Xuan paper”, “Ceramic manufacturing”, and “Su embroidery” can all be recorded, displayed, and interacted with using similar digital fusion methods to enhance audience participation and understanding, and promote the protection and inheritance of cultural heritage. However, there are still some shortcomings in this article. In the experimental analysis part, this article only selects one theme for investigation and analysis, and the sample object coverage is limited. The application of the integration of digital technology and Huizhou ink making skills in more scenarios still needs to be explored. In future research, themes and application scenarios can be expanded, and the application of other digital technologies such as virtual reality in the inheritance of traditional culture

can be discussed, so as to continuously promote cultural innovation, inheritance and development.

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