Digital Brush with Intuitive Operation Design for Children with Visual Interface Feedback

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Abstract: With the advancement of technology and computer equipment, drawing tools for children had become more diversified. This study bases on the visual feedback of intuitive operation for 10-12 year-old children. We are aiming at designing an appropriate interface with operation to create accurate mental models for users in order to improve processing fluency and efficiency. In the first stage, we defined functions over literatures and experiment results before. After that, through focus groups, we explored the possibilities of interface design on each function. In the second stage, this study involved children as subjects to evaluate concepts. Use child's evaluations and judgments to redesign the details of concepts. Finally, through modeling and coding to establish a drawing system for performance test and subjective evaluation. Three findings are described in the last experiment of experimental groups: (1) Better performance in processing fluency. (2) Higher subjective evaluation in effectiveness, satisfaction and conceptual compatibility. (3) Larger drawing spaces make plentiful strokes. The above results show the design process in this research can provide an appropriate interface and drawing experience for users.

Key words: Digital Drawing, Intuitive Operation Digital Pen, Feedback, Usability Evaluation

1. Introduction

Computer aided drawing holds the strength of editing, saving, communication, and interaction, bringing a huge convenience to users. Many operation platforms for digital drawings already exist (such as CrossY、ILoveSketch、VoodooSketch、iCanDraw etc.). According to Brandl, Forlines, Wigdor, Haller, and Shen [1], these digital drawing platforms have set increasing input performance and achieving conventional drawing experience as the final goals. They can be categorized into the following four according to areas of improvement: (1) Stroke input track recognition [2,3,4,5]; (2) Gesture aided or replacement [1,6,7]; (3) Replacement of GUI interface with physical interface [8,9]; (4) GUI redesign and allocation [10,11].

Wu et al. looked into the intuitive operation approach of digital pens/brushes and had concluded that the intuitive operation input mode performs better than the conventional Graphic User Interface point-and-click operation [12,13]. Therefore, this research is based on the intuitive digital pens, discussing its visual feedback interface. The current computer-aided drawing systems, whether it is mouse-operated or digital pen touch-control, are mostly equipped with the Graphic User Interface (GUI). However, current researches have mentioned various different input methods, which should come with compatible interface viewpoints [14,15]. Also, visual can be seen as the most common approach of the human sensing system and recognition behavior; observing the graphic and tracks drawing need to be transmitted through visual recognition. Therefore, this research aims at using the intuitive operation as the basis, discussing the visual feedback interface of intuitive digital pens; collocating it with a compatible interface to improve user performance. Most existing researches on visual feedback and movements discuss the effect of visual feedback on movement reactions, very little start from movement development working towards compatible interfaces. This research not only discusses compatible feedback interfaces, but also the process from interface concept development to the evaluation convergence process, hoping to expand application to related fields.

The purposes of this research are as follow: (1) Discussing the operation interface of intuitive digital pens; (2) Designing visual feedback interfaces compatible with input movements to increasing compatibility; (3) Designing a research method procedure that develops suitable interfaces through movements; (4) Integrating feedback interfaces and physical digital pens into a complete digital drawing system.

With the development of computer technology, the various media not only satisfied more needs of children, also increased their creativity [16]. Lambert and Bard [17] pointed out children ages 10 and above could perform at an adult level during simple operation tasks. In order to integrate the possibility of actual future applications, this research targets senior school children between the ages of 10 and 12. Children at this stage have entered the period of formal operations and are equipped with the ability of understanding abstract ideas and solving various presumptive and deductive problems [18]. Learning with group work has also equipped children with the overall concept, teaching them the ability to observe with objective knowledge and a better learning efficiency for the intuitive digital pen operation. Therefore, it is necessary to develop and discuss a compatible digital drawing platform for children.

2. Methods

The purpose of this research is to create a feedback mode for intuitive digital pens in order to increase operation efficiency and flow during computer-aided drawing tasks. The research procedure is divided into three stages of divergence, convergence, and verify, proceeding with: (1) Digital pen feedback interface concept development; (2) Digital pen feedback mode construction; and (3) Intuitive operation of drawing system verification.

Wu and Chen [13] integrated stroke functions with the conventional drawing gripping position of children, allocating the pencil, crayong, and paint functions on the top, middle, and bottom of the pen respectively. Lines are added to the pen to enable users to change brushes by touching the different textures and changing gripping positions. The color questionnaires showed that in conventional drawings, teachers often provide 12 colors for children to draw (12 colors - 48%；24 colors - 19%；36 colors - 19%). The color-changing function is shown on the interface to be selected by point-and-click. Stroke thickness is switched by changing the angle between the pen and the picture. The more slanting the pen is held, the thicker the stroke produced [19].

Tsai [20] observed children’s behavior while using computer-aided drawing software and found that the necessary functions include brushes, thicknesses, colors, shadings, and eraser, amongst which the eraser uses the end of the pen to complete the action. During their drawing process, the shading function often does not perform as expected due to open or incompletely closed shapes. Therefore, this research plans to list the four functions of brushes, thicknesses, colors, and eraser as major functions of the digital pen for children. Considering the integration of models and programming when combining with other functions, the color change function uses the turning of the pen as input [21]. To conclude, the final intuitive digital pen function and operation approach came up with the functions of brushes, thicknesses, colors, and eraser; it is operated by hand shifting, stroke angle, and turning. Since the thicknesses function and the eraser function have the same way of operation, in the feedback concept developing stage, only the three movements of shifting, angle, and turning are used. Multilevel focus group was used to develop suitable concepts for the selection of the evaluation stage.

2.1 Digital pen feedback interface concept development

Digital pen feedback concept development is processed in multi-levels. Through children focus groups, the referent for each movement is found before professional focus group is brought in [22,23] to design a feedback system for the intuitive digital pen according to graphic association. During this stage of the experiment, the participating children were not informed that the movements are to be used for the design of future digital pen feedback. On top of that, to avoid the effect of the limitation of the controller appearance, daily life pictures were used in the experiment to aid in the defining of various operation movements before the proceeding of participant association. During the experiment, children were only required to come up with graphic nouns associated from each movement themes, or to describe to their peers. Only the graphics that leaves a deeper impression needs to be expressed through drawing. The two levels of digital pen feedback concept development were children focus groups and professional focus groups. The related monitor films on movement association produced by children were brought into professional focus group discussions, based on the design elements in the film, designing a more suitable feedback interface for school children. Also, since professional focus groups include professionals from different fields, on top of developing feasible proposals, we were also able to bring forward details that needed attention in the next stage of concept evaluation and experiment. These are helpful points to the planning and implementing of future experiments.

2.2 Feedback concept evaluation method

Once the feedback proposal for each movement has been found throw concept development, the simulation and prototype operation approach in this stage hope to understand the evaluation of the feedback modes from the participants. During the evaluation stage, participants held the digital pen models to operate given tasks with assigned movements. The feedback interface is simulated by PPT playing the simultaneously. Questionnaires and interviews were given after the simulation. The results were used to select concepts or modify details for the final proposal.

The questionnaire and interview contents were defined by literature reviews. After each operation task, participants were to answer questions on measurement scale of the five criteria of easiness to learn, effectiveness, satisfaction, concept compatibility, and moving compatibility. The concept evaluation experiment included 12 elementary school children (6 students from each 5th and 6th grade). The participants were all first-timers in intuitive digital pen operations with right hands as their preferred hands.

The subjective measurement scale results from the 12 participants were analyzed statistically. The operation movements of brushes, thicknesses, and colors functions each include the following 4 items of feedback interface design, showing in Table 1. Setting the weight of the 5 principles as 0.2, the total score shows the combined evaluation of each feedback concept. The experiment results are analyzed by repeated measures; the LSD post hoc test is used for data that does not violate the assumption of sphericity; however, data that violates the assumption of sphericity needs to be adjusted by Greenhouse-Geisser before the LSD post hoc test. In the repeated measures ANOVA, the feedback concept evaluation results of each function are showing in Table 2.

Table 1. The four combined evaluation values of brushes, thicknesses, and colors

Concept number	1	2	3	4
Brushes	 3.908	 4.305	 3.265	 3.868
Thicknesses	 3.988	 3.962	 3.638	 3.748
Colors	 4.017	 3.232	 4.252	 3.900

Table 2. Feedback concept combined evaluation variance summary analysis

Functions	SS	df	MS	F	Significance	Post Hoc
Brushes	11.724	3	3.908	11.016	.000**	2, 1>4>3
Thicknesses	1.029	3	.343	.534	.662	
Colors	7.087	1.880	3.770	8.502	.002**	3, 1, 4>2

**p<0.01

The final proposal of the feedback mode is achieved by first eliminating incompatible concepts from the subjective measurement scale (Table 2), then to evaluate reasons for better evaluation results from the interview before the final concept revision. Amongst the three operation movements, feedback concepts 1 and 2 for the brushes achieved the highest evaluation in all items. Participants also pointed out the strength of these 2 items repeatedly during the interview, such as the feedbacks showing up for all functions help with the operation and learning, pictures were closely related to daily-life objects, and improves feedback recognition during drawing.

However, even though there is no significance relationship between thicknesses and factors for each concept, and that the evaluation index for each of the four feedback concepts are very close, if we look at the feedback score index distribution, we can see that the four feedback concepts showed a better performance in terms of easiness to learn and concept compatibility than the other three factors. During the interview, we could also feel that the feedback preference and evaluation from each participant did not show agreement like that of the brushes and colors functions. However, by evaluating the interview results of participant opinions for each concept modes, we've obtained results such as obvious increase in the graphics during thickness changes and the graphic increase approach for shading.

In terms of the color feedback mode, if we looked solely at the appearance of the menu, circles showed a better evaluation than bars; as for the switching method, the turning menu or target items each showed different reasons for the different evaluations; participants who gave the turning menu a higher evaluation thought it was more interesting than the conventional way, but for participants who gave turning the target menu a higher evaluation thought it was clearer visually and caused less disturbance during operation.

From the above quantitative and qualitative experiment results, key design factors were brought up, feedback interfaces were revised, and the final feedback mode is showing in Table 3.

Table 3. Intuitive digital pen feedback mode conclusions

Brushes		Integrating concepts 1 and 2, the interface uses the menu mode with the target item changing to a colored picture during function activation.
Thicknesses		Integrating all evaluation factors, emphasizing on graphic increase, showing thin, medium, and thick adjustment conditions with shade intensity.
Colors		Similar to color feedback concept 3, during the switching process, the target item is turned to the top of the menu to show the selection condition. When the pen moves clockwise, the target menu also switches clockwise.

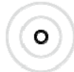
2.3 System Construction and Experiment

The goal of the system construction is to integrate the interface and the intuitive digital pens, also to verify through system construction whether the feedback concept design has reached the expected goal. This system uses a tablet PC as the drawing platform. The model of the pen is constructed by CNC and the signals detected by detection components and transmitted by Arduino. The presentation of the feedback interface is written using Arduino, Serveproxy, and Flash, presenting it on the tablet PC picture. The pen itself is constructed by CNC, as indicated in Figure 1. The research follows the opinions of the comments from the professional focus groups in the concept development stage. Putting into consideration the effects of shadowing on light-sensitive resistance when the pen is turned, a touch-control switch is used to replace it during the model construction stage and the distance between the three keys is shortened to avoid a large hand-moving range during operation. The turning and angle slanting movement detection is detected by a three-axle accelerator hidden at the end of the pen.

Figure.1 Model pen appearance

The intuitive digital pen from this research includes four major functions: brushes, thicknesses, colors, eraser, plus three types of operation movements: shifting, slanting, and turning. The pen is built in with three touch-control switches in the body and a 3-axle accelerator at the end. Apart from the shifting movement which is detected by the touch-control switch, the slanting and turning are both detected by the three-axle accelerator. The user controls the digital pen of which the signals are detected by the response components to transmit to the computer and activate the feedback to show in the center of the screen. The interface forms of each movement are organized in Table 4 below. Apart from showing the whole interface of the activated function menu, the target items are presented using shading intensity or colors. This feedback mode is used to construct the relationship between operation and results.

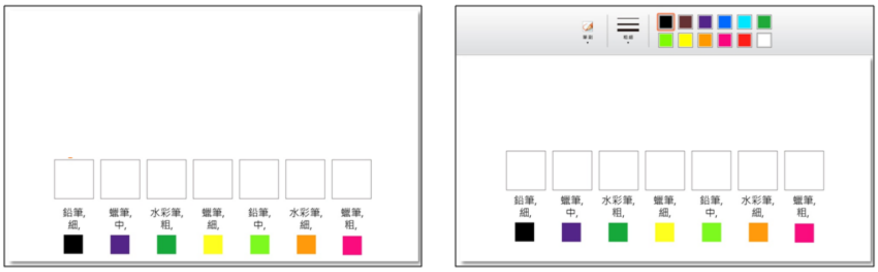
Table 4. Operation movements and their respective interfaces

Function	Movement	Feedback Interface
Brush		
Thickness		
Color		
Eraser		

3. Experiment procedures and contents

3.1 Task operation and subjective evaluation

The task operation stage measures the time participants take to finish 7 tasks with a total of 6 questions. The experiment screen is showing in Figure 2 with the appointed tasks showing under each box. Users are to adjust the digital pen to the corresponding movement before completing the tasks in the boxes from left to right. Same questions apply for the experimental and the control groups in order to compare the operation fluency and the subjective reception differences with the same tasks.



Experimental Group　　Control Group

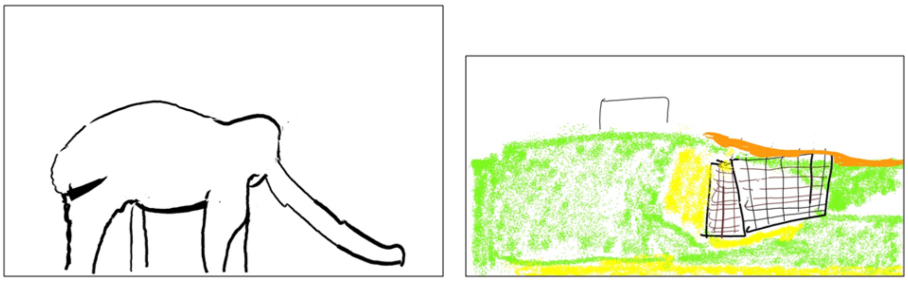
Figure.2 Experiment task operation screen

The subjective measurement scale is based on the intuitive digital pen feasibility targets set by the literature review done during the concept evaluation stage. Upon completion of the appointed tasks, each participant is asked to mark the scales to answer questions on easiness to learn, effectiveness, satisfaction, concept compatibility, and moving compatibility. The participants were trained on task operation within their groups. In order to avoid the effect of experiment order on learning and memory, the participants were divided into even and odd numbers. The odd numbers operated as the experimental group first while the even numbers operated as the control group. This stage of the experiment takes about 30 to 35 minutes.

3.2 Free Drawing

The free drawing experiment records the stroke abundance of the experimental and the control group under different interfaces in order to find out whether the drawing behavior is affected by the interface. To avoid the effect of extensive experiment time on children's emotions, we limited the free time of both groups to 6 minutes.

Other than that, we found in the pretest of the free drawing experiment that the results can be affected by the topic if chosen freely by the participants, which in turn causes the insignificance of the stroke abundance measurements as showing in Figure 3.



Experimental Group Control Group

Figure.3 Pretest results of free drawing

4. Results

4.1 Task operation and subjective evaluation

Table 6. Task operation T test in pairs

		N	Mean	SD	t	df	Sig.
Brush	Experimental	12	21.60	6.56	-3.23	11	.008**
	Control		23.79	5.52			
Thickness	Experimental	12	19.00	3.39	-.79	11	.448
	Control		20.40	4.73			
Color	Experimental	12	54.23	8.34	-3.11	11	.010**
	Control		59.88	9.01			
Combined task 1	Experimental	12	64.03	7.29	-4.66	11	.001**
	Control		77.38	14.27			
Combined task 2	Experimental	12	72.13	6.24	-3.29	11	.007**
	Control		82.54	10.23			
Combined task 3	Experimental	12	88.65	15.79	-.60	11	.563
	Control		91.76	15.85			

**p<0.01； 2-tailed test

Task completion time in seconds is used to compare operation fluency difference between the experimental and the control groups using the T test. Table 6 shows significant difference in brush, color, and combined tasks 1 and 2. The statistic data also shows that the above four items presented a shorter continuous movement time in the experimental group than the control group. With the same digital pen and the same tasks, the experimental group performed continuous tasks in a shorter than the control group; this shows that the feedback interface of the experimental group helps participants with shortening the time for continuous tasks, which in turn increases operation fluency.

The subjective evaluation scale is used the same way as the scale used in the concept convergence stage of this research. The two groups answer the same questions and the participants subjectively evaluate and connect to the right positions. Paired T test is also used to compare the difference in subjective evaluation between the two groups. The principles used in the concept evaluation stage are used again in system evaluation on the 5 interface design questions. Participants have to answer the questions according to the level of agreement where 1 stands for completely disagree and 5 stands for completely agree. The results of the paired T test are showing in Table 7. The subjective evaluation results of effectiveness, satisfaction, and moving compatibility all showed a significant difference. We can also see the obvious higher evaluation in the experimental group than the control group.

Table 7. Subjective measurement paired T test

		N	Mean	SD	t	df	Sig.
Easiness to learn	Experimental	12	4.19	.47	1.79	11	.101
	Control		3.77	.75			
Effectiveness	Experimental	12	4.35	.64	3.35	11	.007**
	Control		3.53	.89			
Satisfaction	Experimental	12	4.48	.67	5.28	11	.000**
	Control		3.77	.71			
Concept compatibility	Experimental	12	3.83	.61	-.75	11	.468
	Control		3.98	.63			
Moving compatibility	Experimental	12	4.58	.58	3.04	11	.011*
	Control		3.91	.77			

* $p<0.05$, ** $p<0.01$; 2-tailed test

4.2 Free Drawing

Table 8. Stroke abundance paired T test

		N	Mean	SD	t	df	Sig.
Brush	Experimental	8	3.88	1.73	1.62	7	.148
	Control		2.75	1.28			
Thickness	Experimental	8	31.63	9.12	3.61	7	.009**
	Control		24.13	5.79			
Color	Experimental	8	7.63	3.20	.48	7	.644
	Control		7.13	3.36			
Eraser	Experimental	8	1.63	1.30	.20	7	.850
	Control		1.50	1.31			

** $p<0.01$; 2-tailed test

The free drawing experiment records the function switching frequency of the experimental and the control groups. When the stroke is made to switch between functions, the data will be recorded. The system recorded data is analyzed by paired T test for the drawing performance. Table 8 shows only a significant difference in switching frequency in terms of thickness. We can also know that the switching frequency of the experimental group is clearly higher than that of the control group. Under the circumstances of no significant difference between brush and color, we can see from the appendix that under the effect of the background picture, participants produced similar drawing contents. However, since the experimental group has given participants more room for drawing, it could be the factor for the obvious thickness difference.

5. Discussion

During concept evaluation, the subjective scale showed similar scores between turning the whole color menu 1 and turning the target menu color 3. If color 1 was chosen at the beginning, the problem found during system verification could be solved. It is compatible to the operation movement of the current system settings without creating a difference between the top and bottom operation performance. However, color 1 was not chosen for the final proposal because during the interview, it was pointed out that even though turning the whole menu is more interesting than turning the target, it created dizziness with time. Plus the fact that system design principles mentioned the consideration of user recognition pressure load, therefore color 1 was not used. Collocating with the turning interface, since the operation movement and the picture turning range are vertical to each other, there are strengths and weaknesses with both colors 1 and 3. The improvement method for the two proposals was considered after system verification. Color 3 revises the slanting angle of the digital pen within the system before the turning of the pen, creating a horizontal turning range between operation and screen. Color 1 adjusts the details through interface design, using colors or the proportion distribution of the screen to preserve the features of the turning menu and lower the negative effect of screen vibration at the same time.

The subjective scale showed higher scores in terms of effectiveness, satisfaction, and moving compatibility for the experimental group. This shows that the design proposal obtained by focus groups and operation simulation was able to reach a certain level of acceptance with the users. Although there was no significant difference in easiness to learn and concept compatibility between the two groups, it was understood from the interviews that since the feedback interface used for the control group was Paintbrush, users with Paintbrush experience were more familiar with the control group interface, which indirectly affected the anticipation level and evaluation results. Other than that, whether the experimental or the control group is operated first, participants had to practice using the digital pen before the task. Only participants with familiar operation are able to give meaningful evaluations afterwards. However, due to familiarity with the digital pen, the interface has less effect on the easiness to learn of pen operation. The stroke abundance experiment results show that the modified experiment method has solved the problems found in the pretest. By giving the same background picture topic and limiting the drawing time to 6 minutes have contained the free drawing contents to elements of the sun, cloud, tree, or grass. This has also caused the non-significance in the stroke abundance of brushes and colors due to similar drawing contents. However, under the adjustment to reach similar level of answers in the experiment, the experimental group still presented a higher switching frequency in thickness than the control group. This can be predicted to be due to the preserved drawing area for the experimental group creating a larger drawing range for the users. The results also showed a higher frequency in smearing strokes with the experimental group.

6. Conclusion

Since intuitive digital pens use different movements to the replace conventional graphic interface, we used sight feedback to provide users with system messages. Apart from using different ways to diverge the design and feedback concepts and converge to evaluate, the system practice also confirmed the hypothesis made in the beginning on the interface form that provides users with larger and cleaner drawing spaces and better fluency compared to the conventional graphic interfaces.

Objects implied by operation movements are found in daily life in order to gain a better understanding of the way user interfaces are presented and to focus on the principle of compatibility in design. Simulation and subjective evaluation ensure feedback compatibility of the final proposal, also ensure user recognition and reaction speed.

Elementary school children have set class times at school and professionals from design and educational backgrounds also have their own schedules. In this research, multi-level focus groups are used to avoid the above problem and to select suitable contents from the previous stage of discussion to ensure the correct direction.

During the concept development stage, this research used multi-level focus group, concept development matrix, and implied objects to help with the feedback design divergence. These procedures are helpful to future development and feedback interfaces compatible with operation movements such as related fields of gesture input or body motion control.

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