A DRAWING LEARNING SUPPORT SYSTEM BASED ON THE DRAWING PROCESS MODEL

Takashi Nagai
Graduate School of Science and Technology,
Shinshu University, Nagano, Japan, and
Mizue Kayama and Kazunori Itoh
Department of Computer Science and Computer Engineering,
Faculty of Engineering, Shinshu University, Nagano, Japan

ABSTRACT The purpose of this study is to develop a drawing learning support system using a networked environment. In this paper, firstly, we describe the results of a potential assessment for our system. Two assessment approaches are shown. One assesses the possibility of using a digital pen as a drawing tool. The other assesses the effectiveness of drawing learning support based on the reuse of the drawing process of both learners and experts. Secondly, the drawing process model (DPM) for supporting individual drawing learning is also discussed. Finally, we show three examples of learning with our system.

KEYWORDS Drawing Learning, Learning Support System, Online Class, Drawing Process Model, Digital Pen.

1. INTRODUCTION

Art education in a networked environment has been introduced recently. However, there are some limitations related to functions and contents for basic skill learning such as drawing, painting, and sculpturing (Draw23, Drawspace, Ferraris and Martel 2000, Open Dictionary, Tweddle 2008, University of the Arts London). Drawing is one of the fundamental skills in art education. All beginners must acquire these kinds of skills first (Sato 2004, Sekine 1984). Learning related to art requires repeated practice with a trial-and-error process (Bernstein 1967, Latash 1998, Latash 2002, Takagi et.al. 2003). Therefore, to learn drawing is categorized as skill-learning (Furukawa 2004). In this type of learning, novices cannot recognize whether or not they draw correctly and appropriately. As a result, their learning becomes slower and more redundant.

The purpose of this study is to explore a support system for beginners in drawing in a networked environment. Learners can receive advice and assessments from art experts without time and/or place constraints by using the proposed system. We investigate the possibilities of online supported drawing learning. Two key factors are introduced: a digital pen as a drawing tool, and a drawing process model (DPM).

In this paper, firstly, we will discuss the possibility of using a digital pen (Anoto Group AB) as a writing tool and the effectiveness of drawing learning support in a networked environment. Secondly, we consider the DPM and its application to individual learning support. Finally, the system interfaces are shown.

2. ONLINE DRAWING LEARNING SUPPORT

The major difference between an offline drawing class and an online drawing class is the availability of instruction during learners' drawing. The instruction for the learners' drawing process is more important than instructional comments for his/her work. Therefore, quick and personalized feedback from a tutor is an indispensable function for a networked learning environment. In this study, the learner's drawing process that is recorded by a digital pen is reused in order to replay and view his/her drawing process. To generate an evaluation for the drawing process automatically, this data is also reused in the system we propose.

A learning activity is started after the tutor defines a learning task in the learning management system. The following flows are ideal learning processes in our learning environment shown in Figure 1:

1. A learner draws his/her work with a digital pen.
2. Both of the learner's drawing process data and his/her work are registered in the learning management system after his/her drawing.

[Interaction with Learner and Tutor via System]

3. A tutor evaluates a learner's work by replaying his/her drawing process. Then the tutor adds some advice to both the learner's drawing process and his/her work. This information is registered in the learning support system.
4. A learner takes the tutor's comments that are annotated for his/her own drawing process and work from the system.

[Interaction with Learner and System]

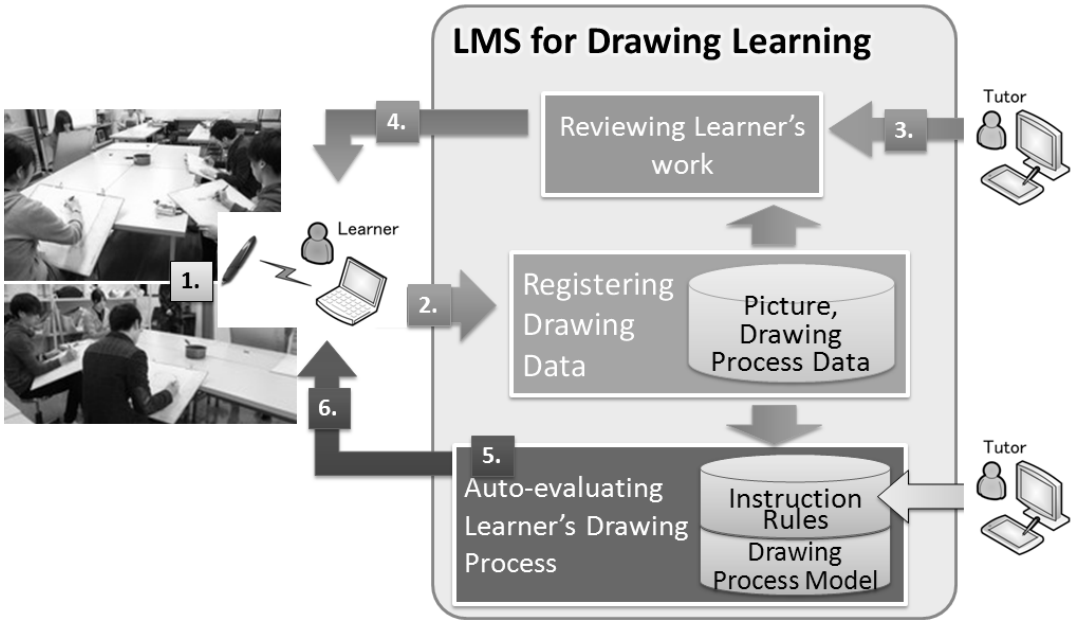


Figure 1. Learning flow with the proposed system

5. The learning management system diagnoses the learner's drawing process based on the DPM. The instructional rules that are defined by tutors are used in this evaluation.
6. The learner is given an auto-evaluated result that is the annotated drawing process based on the instructions for the relevant drawing lesson.

3. BASIC STUDY

3.1 REVIEWS BY ART EXPERTS

We interviewed five experts who are also teachers in an offline drawing class in order to clarify the effectiveness of the drawing learning support in a networked environment (Nagai 2009). All the experts tried using the prototype model of the system before this investigation. Previously, some students drew the same motif with both pencils and digital pens. Examples of these results are shown in Figure 2. Experts replayed and reviewed the learners' process data by using our system. The following are comments from them:

- Tutors are able to review the learners' drawing process and work after they finish their work. Therefore, tutors can give

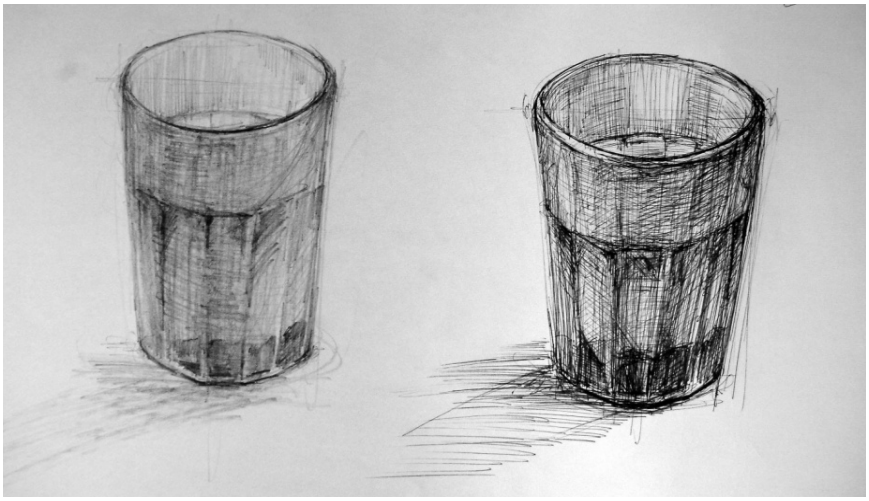
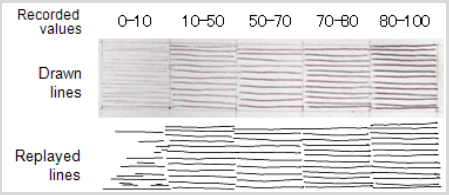
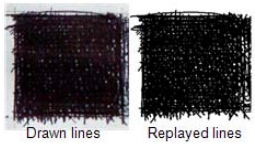


Figure 2. Examples of picture drawing with a pencil (left) and a digital-pen (right).

Table 1. Four specifications of the digital pen

Evaluated Item	Content	Results
Maximum operating time	Continual drawing time. How long a fully-charged battery takes to run out of power.	210 min. (Avg., 5 trials) Max. 218 min., Min. 199min.
Minimum writing pressure	Gradually touch the pen tip to the paper, then measure the alteration of pen pressure and the consistency of drawn lines on the paper.	Thin lines (but visible) could not be recorded. Meanwhile, some lines, when the pen pressure was zero, could be recorded. 
Maximum drawing values	To check the reproducibility of dense lines, some lines are drawn to make a crosshatch in the specific field.	The digital pen can reach the upper limit of density corresponding to a ballpoint pen. 
Maximum and minimum inclination angles	Tilt the digital pen right and left.	$43° \le \theta \le 137°$

adequate guidance that each student wants. Tutors can avoid inappropriate assessments since they can check the learners' entire drawing process and work.

- Tutors are able to present the specific assessment directly to learners. Learners would not forget what was discussed in their class because the learners can repeatedly confirm what tutors corrected.
- Learners are able to recognize the incorrect way of using the digital pen when they replay their own drawing.

The learners' drawing processes were replayed and reused for detailed analysis by experts. That is to say, the need for reviewing the learners' drawing process was confirmed and the demand for drawing learning support in a networked environment was shown.

3.2 DIGITAL PENS AS DRAWING TOOLS

Digital pens have been powerful tools in our lives since the 1990s (McCullouch and Gunn 1993, Yen and Gorman 2005, Dykes and Benoit 2006). In the field of learning and education, much research using digital pens has been reported (Chiueh and Deng 2000, Miura 2005, Chuang 2006, Richter 2012). In this research, a digital pen was used to record learners' material or educators' activities. They just shared or viewed, and no analysis was done on the logged results.

In this study, a standard digital pen is used as a drawing tool to record the learners' drawing processes. Four items were examined to evaluate the possibility of using a digital pen as a drawing tool. Table 1 shows these results. These results were shown to five experts, and then they tried to express some drawings with this pen. We conducted interviews with these experts about the possibility of the digital pen. All the experts accepted the fundamental capability of this writing tool.

At the same time, they also pointed out the need for adequate drawing tasks to suit those limitations shown in Table 1. Moreover, the following demerits of the digital pen were discussed in comparison with a pencil:

- Erasing is not possible after drawing
- Line width is fixed
- Ways of expression are limited

As a result, all the experts agree that this pen could be used as a drawing tool if users of this system are only beginners. The demerits previously mentioned would work well in beginner level lessons. Thus, the possibility of a digital pen as a drawing tool was shown.

4. DRAWING PROCESS MODEL (DPM)

Table 2. Seven drawing steps

1	• Carefully observing to see the drawing subject.
2	• Interpreting the positional relations of each parts of the drawing subject.
3	• Fixing the composition with regard to the balance of the drawing subject and a drawing paper.
4	• Capturing the form of the drawing subject as a set of basic shapes.
5	• Analyzing the design of the subject and capturing their concrete shapes.
6	• Adding the texture to the drawing subject.
7	• Adding finishing touch to the drawing work.

In this study, the learner's drawing process is reused in two evaluations. One is the tutors' evaluation, and the other is the system's evaluation. For the latter, we implemented the automated evaluation function based on the DPM. This model consists of 3 types of parameters. They are the drawing step, the drawing phase and the features of the drawing strokes (Nagai 2011).

4.1 SEVEN DRAWING STEPS

In an interview with five art experts, we collected the drawing processes of experts. Then, we formulated the seven step model as a hypothesis for simplification of an artist's drawing process. The contents of each step are shown in Table 2.

"Drawing is seeing" (Ernest 1985). Hence, the first step is carefully observing to see the drawing subject. The relationship between the light source and the drawing objects is also checked in this step. Then, in step 2, the relative locations of the objects are confirmed based on the vanishing points. In step 3, the composition of this picture is defined. The drawing area is fixed on the drawing paper. In step 4, the outlines of the drawing subject are expressed in simple lines in a balanced way. The rectangle, the oval, triangle, straight line, and simple curve are used consciously in this step. The size, the location, and the direction of each object are also pictured in this step. In step 5, shading is added. Various values of light and dark are expressed in a drawing. The shading techniques become complex for a square pillar, a cylinder, and a sphere in this order. Shading should be added first to objects whose outline shapes are square pillars, second to cylinder shapes and then finally to spheres. In step 6, the learner checks the material of each object, and then expresses its texture in drawing. Finally in step 7, the finishing touches are added. The learner draws details of each object. The learner checks the design of each object. The balance of the total subject is also considered in this step.

4.2 THREE DRAWING PHASES

We found three different drawing phases in the time variation of the drawing strokes and the pen pressures of a digital pen from the quantitative investigation by the art experts. Figure 3 presents the features of strokes and pen-pressures of these three phases.

Two criteria are used to divide each phase. One is when both the number of strokes and the pen-pressure become zero. The other is the difference in the number of strokes or the average pen-pressure. Two divisions that are detected by these rules are shown by the rectangular areas in Figure 3.

According to the quantitative features of the drawing process shown in Figure 3 and the drawing results shown in Figure 4, the features of each phase can be described as follows:

Phase A [Outlining]: The learner interprets the drawing composition and the outlines of the whole object by using simple lines to define the proportion in a perspective way.

Phase B [Shading]: The learner draws the drawing subject totally and adds shade for whole parts.

Phase C [Texturing]: The learner adds the texture of the subject in detail. He/she fixes the balance of the subject on the drawing paper.

The boundary of each phase in the drawing process is determined mainly based on the changes in pressure. In this study, the state of the pressure changes in drawing strokes is called "changes in pressure". In an ideal drawing process, the artist outlines the motif in the first stage of his/her drawing (see Step 3 in drawing steps). In this stage, an ideal artist draws a

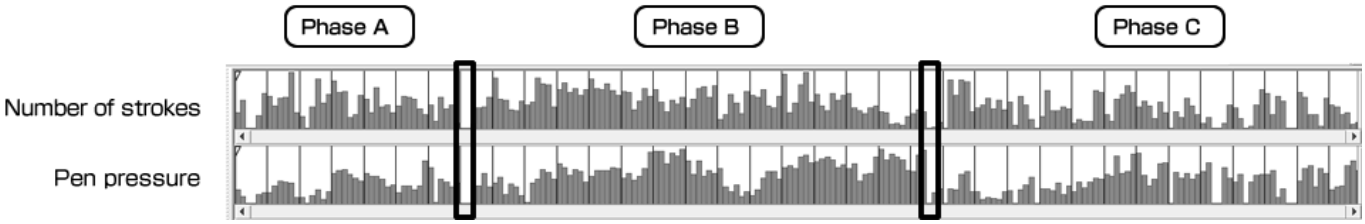


Figure. 3. Three phases in the drawing process

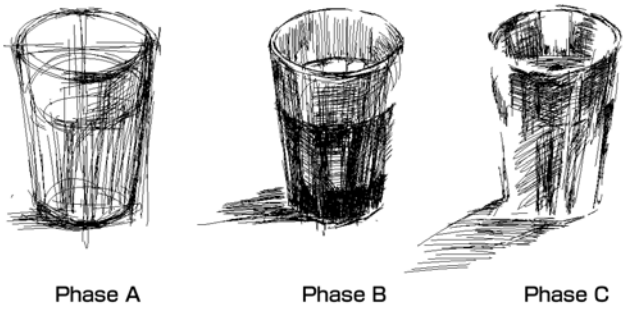


Figure 4. Examples of Drawing Results of each Phase

Table 3. Seven features of the drawing stroke and their parameters

Phase	Stroke				Stroke Set		Drawing Area Ratio for a Paper
	Number	Pressure	Changes in Pressure	Line Types	Size	Locality	
A	Small	Low	Inconstant	Straight lines & Simple curves	Small	Sectional	High
B	Large	Mixed [low/mid./high]	Show a inconstant trend	Complex	Large	Total	High
C	Medium	Mixed	Show a constant trend	Complex	Small	Sectional	Low

rough line using low pen pressure, and draws the outline of the motif using a high pressure line. Therefore, the pressure at this stage tends to be lower, and the state of change is not constant. Therefore, the drawing section which satisfies the following three conditions is identified as Phase-A.

- There are multiple sections where the average pressure is zero or close to zero.
- The state of pressure change does not tend to be constant.
- The ratio of the area of the drawing in that section to the area of the final drawing is more than 75%.

The process parts for Phase-B and Phase-C are selected from the whole drawing process other than the section which is assigned to Phase-A. At first, our system divides the selected parts into 10 blocks in the same time span. In each block, if its state of pressure change does not show a constant trend, the block is assigned to Phase-B. Also, if it shows a constant trend, the block is assigned to Phase-C. Then, the sequential blocks in the same phase are grouped. Two divisions that are detected by these rules are shown in Figure 3.

4.3 SEVEN PARAMETERS OF DRAWING STROKE FEATURES

We have to define concrete and objective features of each phase in order to define these three phases of the drawing process. Seven parameters are shown in Table 3. They are the number of strokes, the stroke pressure, the changes in pressure, the line types, the degree of assembled stroke size, the dispersion of the drawing area, and the ratio of the drawing area. The number of strokes and the pen pressure are relative values in the drawing process. The size and the dispersion of the stroke sets are relative values on the drawing paper (or entire drawing area).

Table 4. Relationship of the drawing steps and the drawing phases

Phase	Steps	Time of appearance
A	1, 2, 3, 4	Not at the end
B	1, 5	After Phase A
C	1, 6, 7	Not at the beginning

Each parameter is expressed in more than two levels. The number of strokes is expressed as small, medium, or large. The pen pressure is expressed as low, medium, or high. The changes in pressure are expressed as non constant or constant. The line types are point, straight-line, simple curve, or complex line (includes curve). The size of the stroke sets is large or small. The locality of the stroke sets is sectional or total. The ratio of the drawing area is high or low.

4.4 RELATIONSHIP BETWEEN THE DRAWING STEPS AND PHASES

We try to summarize the relationship between the drawing phases and the drawing steps. Phase A corresponds to steps 1, 2, 3, and 4. Phase B comprises steps 1 and 5. Phase C covers steps 1, 6 and 7. Phase A tends to appear at the beginning of the whole drawing process. Phase B appears after phase A and/or before phase C. This phase commonly does not occur at the beginning or end. Phase C often appears at the end of the drawing process (see Table 4).

4.5 DRAWING EVALUATION WITH THE DPM

Our DPM was developed by an inference engine that is able to detect the appearance of these three drawing phases based on their geometrical features shown in Table 2, 3, and 4. Our system arranges the learners' drawing processes by using the six parameters shown in Table 3. Then they are divided into the three phases. The proposed system is able to provide some advice for learners based on the DPM. For instance, if a given task is to draw a glass on a table, many beginners tend to start drawing from the configuration of the glass. Advice in this case is to explain to a learner that you had better draw a simple rectangular solid in the perspective way. In addition, the lines of a simple rectangular solid are auxiliary lines. Therefore, tutors should instruct learners not to draw those lines thickly. The final work is not affected much by the draft if learners draw incorrect lines with less pen pressure.

Figure 5 shows the drawing process viewer that our system provides. The upper part of this viewer is an area for replaying the drawing process and showing the instructional information. Two types of advice are added to this drawing: instructional comments and instructional drawings. The former is shown in the timeline bar in the viewer. A comment is linked to a specific point in time when the learner performs an inadequate drawing action. The latter is also connected to a point in time. In this case, an instructor adds red lines to point out error positions, and adds the comment "represent the outline of the vase". The lower part is a graph area. This area includes six graphs that indicate the seven features of the drawing process: the number of strokes, the pen pressure, the line types, the size of stroke sets, and the drawing locality and ratio of drawing area.

The red arrow on the far left shows the first instructional comment for this drawing. Learners obtained the following advice from our system: "Draw some simple curves with high pen pressure to express the outline of the subject. Observe the drawing objects more carefully. Capture each object as a simple configuration."

5. DPM-BASED DRAWING LEARNING

5.1 CLASSROOM LEARNING SUPPORT

Figure 6 shows the drawing learning support functions of our system. Learners upload their drawing process data to our system after completing their drawing. The tutor of this class and all of the class members are able to access the portfolio pages for today's results (Figure 6 upper left). A member of this class is able to refer to the drawing pictures and these process data in this portfolio. A drawing process viewer page is shown to him/her when a learner chooses a learner's drawing result (Figure 6 upper right). A learner can replay the drawing process from any point in time. This viewer is able to show graphical evaluation results for six parameters in time series graphs.

Our system generates some advice for the drawing process based on these results. The tutor's comments are also confirmed on this page. The evaluation results from both the system and the tutor are added to the time series. The learner can recognize which points are wrong and correct the drawing.

Referring to experts' and others' drawing processes helps a learner understand the advice from the system and the tutor. Moreover, comparing one's drawing process with others could help them find new techniques and/or drawing methods. Learners hand in their drawing processes and then obtain the tutors' feedback as individual learning support tools (Figure 6 lower part).

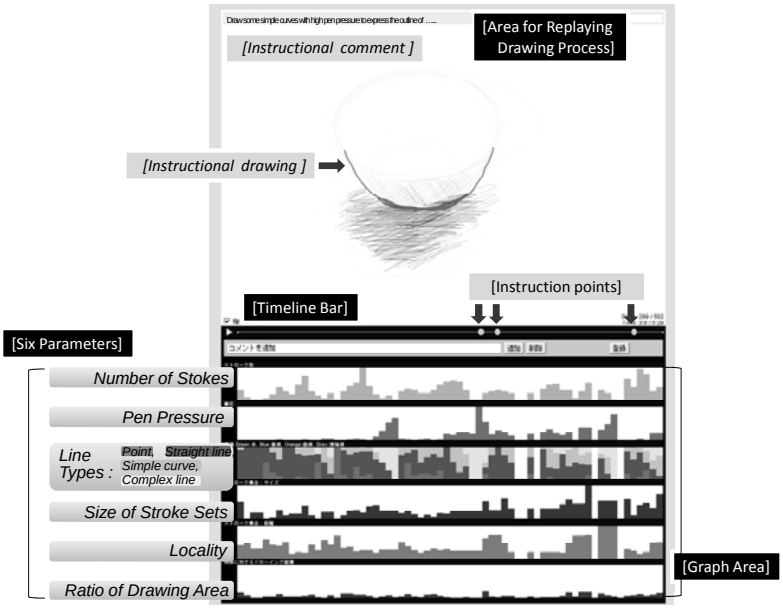


Figure 5. An example of the drawing process viewer
(A tutor adds red lines for pointing out error position, and adds the comment "represent the outline of the vase".)

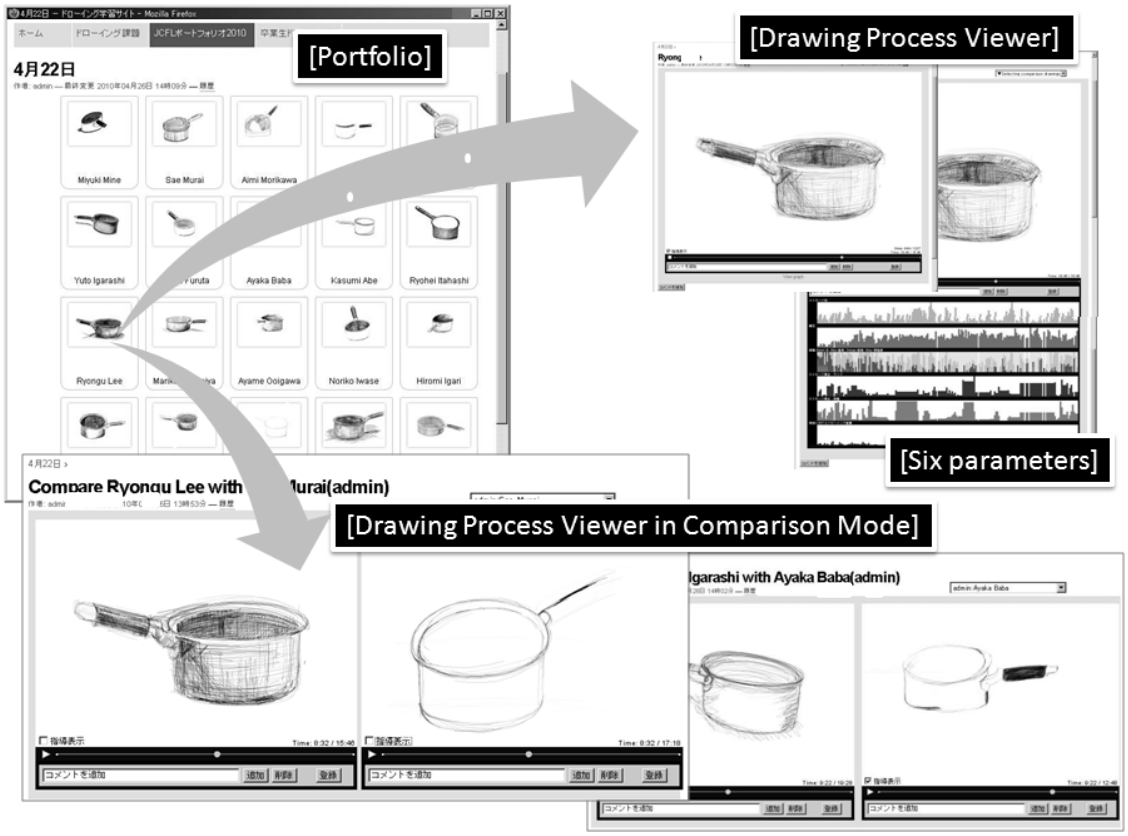


Figure 6. Examples of the System Interfaces
(The portfolio viewer [upper left], the drawing process viewer with/without six graphs of drawing process parameters [upper right], and the drawing process viewer in comparison mode [lower part].)

5.2 INDIVIDUAL LEARNING SUPPORT

This function is used between the time when a learner finishes his/her drawing and the time when a teacher gives this learner some direct instructions. To support the individual drawing learning, learners' drawing processes are analyzed based on the DPM. At first, our system separates the learner's drawing process into three drawing phases. Then, the geometrical features of each phase are compared with the DPM. Based on this analysis, our system generates advice for that learner. Timing and content of that advice are determined. There are two types of advice: instructional comments with short sentences and instructional drawings as models.

The supporting functions for individual drawing learning are as follows:

- Replaying one's own drawing process.
- Synchronous replaying of one's own drawing process with those of other learners / art experts / instructors.
- Showing the location of the 3 drawing phases in a learner's drawing process.
- Total advice comments for the whole drawing work.
- Instructional comments and drawing for a sectional drawing.
- Introduction to some drawing techniques and exercises which should be mastered by this learner.
- Introduction to the drawing work of other learners / art experts / instructors as a model.

6. BASIC EVALUATION

6.1 SHORT-TERM EXAMINATION

The educational effectiveness of our model and our method for learning support was examined at a professional art school in Japan. The subjects of our system are art school students, who want to enter an art college or university abroad, like London or New York. Additionally, our main students are novice-learners of drawing. Some subjects in this experiment are mature-learners of drawing. They have graduated from art colleges or universities in Japan. The experiment period was 1 month (from April 2010 to May 2010). During this period, the art school did not give their students any kind of drawing classes. The subjects were 18 students. 15 of them were novice-learners and the other 3 students were mature-learners. The subjects were asked to use our tool for a month for their individual learning. The frequency of use was not specifically mentioned.

In this experiment, we focus on the appearance of Phase-A in the learners' drawing processes. Phase-A is the most important part to sketch a motif. However, many instructors in art school do not tend to teach this matter explicitly to their learners. Before this experiment, Phase-A appeared in the drawing processes of the 3 students who were not novices. The drawing processes of the other 15 students, by contrast, did not show Phase-A. After this experience, 3 students in the novice-learners group showed Phase-A processes, and 3 students in the mature learners group also showed Phase-A processes.

The work in Figure 7 is the final drawings of two students whose drawing process did not have Phase-A before the experiment. Figure 8 and Figure 9 show the drawing results in each phase for these students. The upper part of each figure shows a graph of the changes in pressure in a time-line and the detected phases. The lower part shows the drawing results in each phase. From these results, two problems can be pointed out.

- Learners wrote some clear lines with high pressure from the beginning.
- Learners did not draw the whole shape of the motif at the beginning.

Thus, without making an outline, these learners were trying to show the form of a motif immediately. For example, in the section 1 in Figure 8, you can confirm that this learner started his drawing without capturing the outline of the motif. This phenomenon is one of the specific features of the drawing process of a beginner.

During the experiment, our system checked for the appearance of Phase-A. If Phase-A did not appear, some text comments (for example "You should learn the techniques to form a composition by drawing a simple shape.") are given to the learner at the appropriate time. The system also introduces a link to the related exercises. In these exercises, a learner is asked to draw some lines with the indicated pen pressure, and/or to draw the whole outline of the motif with low pressure. At the same time, the system suggests to refer to an expert's drawing process to form the composition in simple shapes.

After the 1 month experiment, for 6 out of 15 novice students whose drawing process did not include Phase-A, a section of Phase-A began to appear in their work. These students effectively used our system in their individual learning. The other 9 students could not draw an outline of the motif at the beginning of their drawing yet. The frequencies of use of our system were lower than the students who were able to improve their drawing. Figure 10 shows the final work after the experiment. Figure 11 and Figure 12 show the drawing results of each phase for two students (the same students as Figure 8 and Figure 9). The quality of the final work was not high (almost the same level as 1 month before), but in these results, learners tried to make the outline of the motif using low pressure at the beginning of their drawing (see section 1 in Figure 11 and 12). Similar results were seen for other subjects.

The following comments were collected from the subjects after the experiment.

- I can replay my own drawing process by using this tool, so I can carefully and repeatedly check my bad habits.
- I can view and replay the drawing processes of others, so I can better understand the necessary techniques.
- The timing of advice and the timing of bad drawing is synchronized, so I can easily recognize my drawing points which need amendment.

From these results, we can see the potential for educational effectiveness of the DPM based individual drawing learning support.

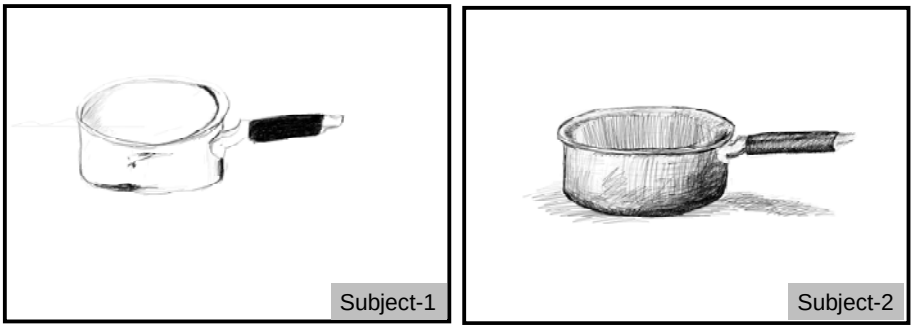


Figure 7. The final work prior to the experiment

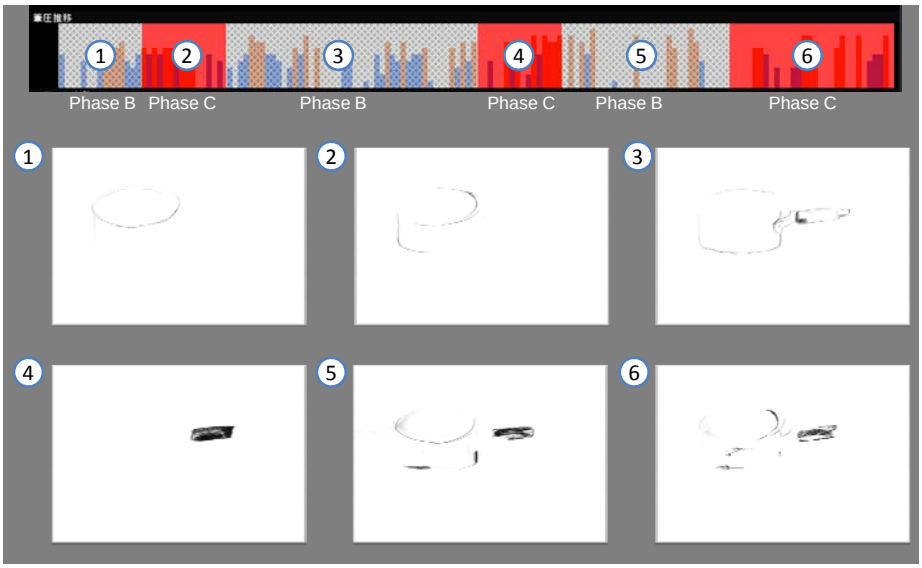


Figure 8. The drawing results in each phase prior to the experiment [Subject-1]

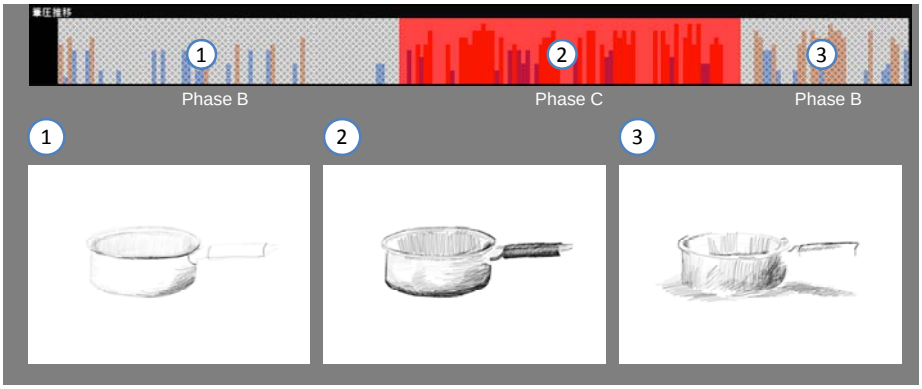


Figure. 9. The drawing results in each phase prior to the experiment [Subject-2]

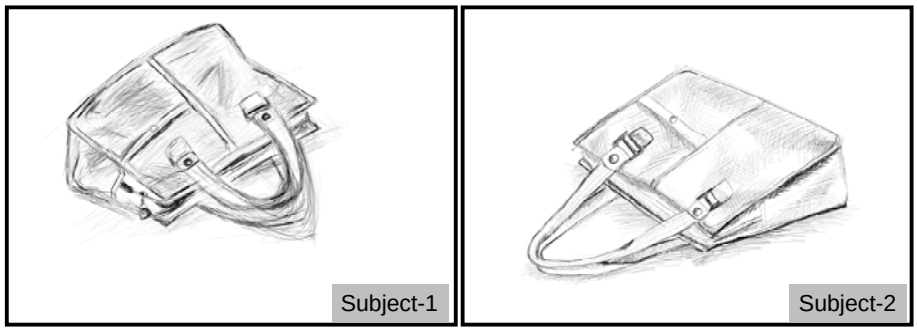


Figure 10. The final work after the experiment

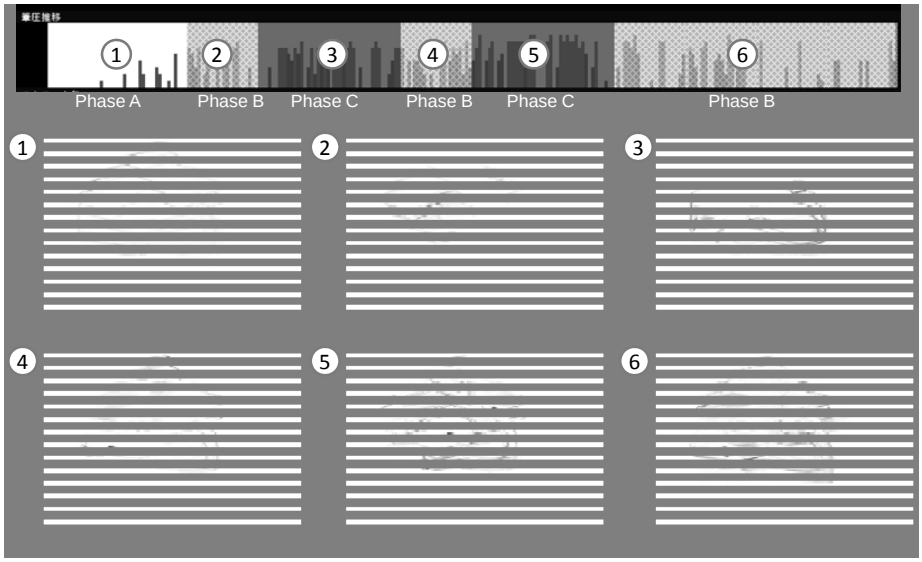


Figure 11. The drawing results of each phase after the experiment [Subject-1]

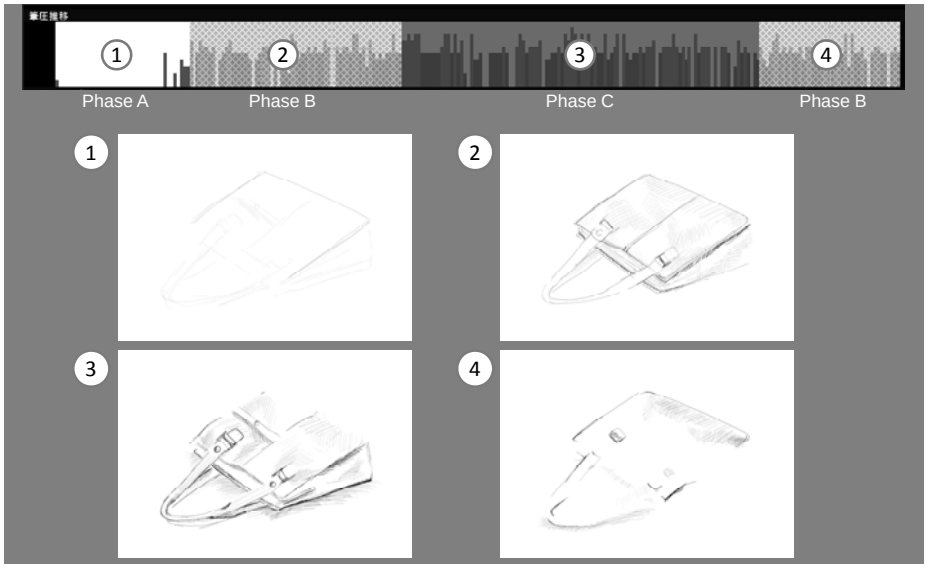


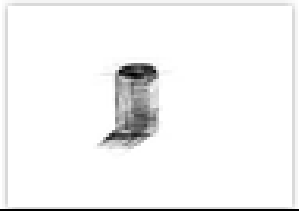
Figure 12. The drawing results of each phase after the experiment [Subject-2]

6.2 LONG-TERM EXAMINATION

As a next step, we wanted to confirm the effectiveness of the DPM based instruction by real tutors at the professional art school. An experiment was held at the same school in 2011. The experiment period was 6 months, which was from April 2011 to September 2011. During this period, the art school held regular classes about not only drawing but also painting. The number of subjects was 16. All of them were novice learners. We also had 3 tutors as our subjects. 2 tutors were full time workers at that school, and 1 tutor was a part-time worker.

During this experiment, a learner could refer not only to his/her self drawing process but also others' drawing processes via our system anytime and anywhere they wanted. 6 motifs, which were selected by the tutors, were used in this experiment (see Table 5). All motifs were different from each other.

Table 5. Motifs for each month

Month	Motif	Example drawing
April	A cylindrical vase	
May	A bucket and a brush	
June	A bottle and a block	
July	A potted house plant	
August	An electric kettle and its power cord	
September	A saucepan and its lid	

The tutors named the drawing with a digital pen “digital drawing”. During this experiment, after the digital drawing, a tutor gave some advice face to face to the learner based on the analysis result of our system. This mentoring was done once a month. We evaluated these three points in this experiment.

- Improving the appearance of Phase-A.
- Increasing the number of strokes.
- Fostering the awareness and reflection of both student and tutor users.

6.2.1 Phase-A appearance

Figure 13 shows the changes in the number of students’ drawings which include Phase-A. Each motif, which was the drawing result of one subject in this experiment, is shown in this figure. From April to May, and May to June, the number increased. Though, from July to September, the number decreased. According to the tutors, the reason for this change was as follows. Students got some drawing techniques from June to July. Rather than tracing basic drawing steps, the learners began to focus on making the drawing beautiful or nice looking. In addition, the complexity of the motif was another reason. The motifs in July, August and September had many small parts which had various kinds of lines, curves and shapes. Therefore, these drawings needed higher level techniques.

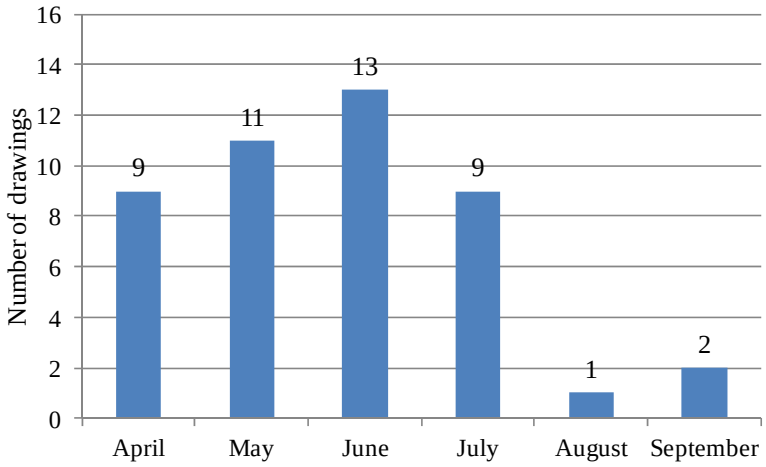


Figure 13. The changes in the number of students’ drawings which include Phase-A

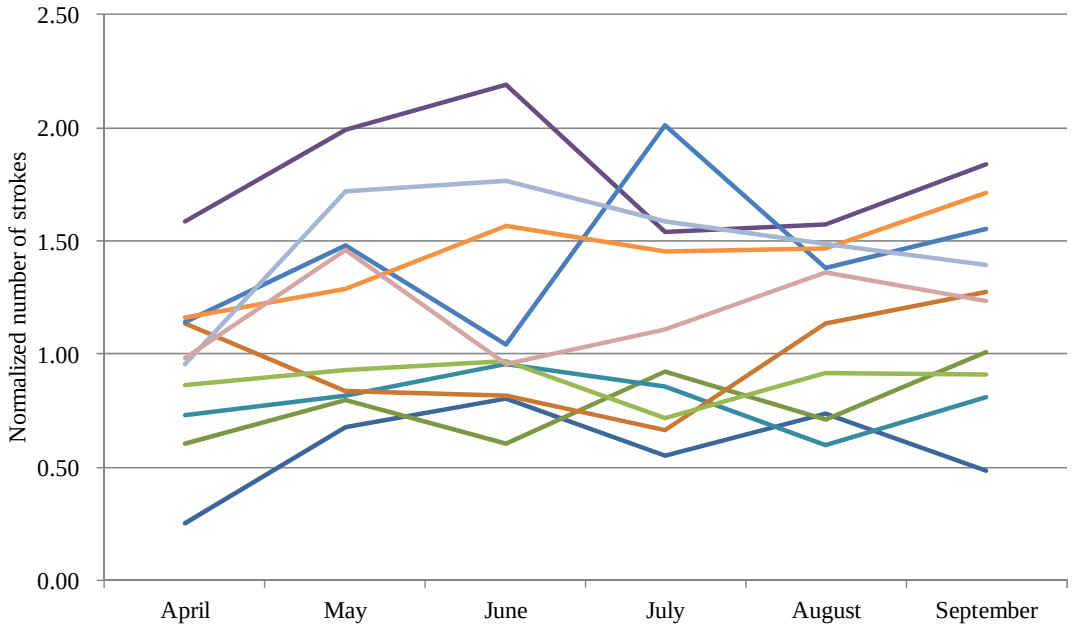


Figure 14. The changes in the normalized number of strokes used by “Active Learners”

6.2.2 The number of strokes

We changed the motif each month. Therefore, the numbers of strokes for each drawing needed to be normalized by the average number of strokes. Of all our subjects, 10 of the 16 students took advantage of the system frequently. We call them “Active Learners”. The other 6 students were “Passive Learners”. Figure 14 shows the changes for "Active Learners" during this experiment. By comparing April and September, the normalized numbers of strokes increased for all "Active Learners". They improved their numbers of strokes by 135% on average (max.:190%, min.:105%). The tutors agreed with this result, because through face-to-face mentoring, learners whose progress was observed were in the "Active Learner" group.

6.2.3 Awareness and reflection of users

To discuss about the third point, we want to focus on 2 “Active Learners”. In the case of Student-1, Phase-A started to appear in June. The review comment from this student was “I did not know what to do and how to study drawing at home. However, thanks to this tool, I can get a clue of how to study drawing.” Furthermore, in the case of Student-2, Phase-A began appearing in May. The comment from this student was “By using this tool, I can play back my own drawings. In addition, since I can browse other learner's drawing process, I can agree with what the teacher pointed out for my drawing. So, I can draw the next motif with awareness of those points.” After Phase-A started to appear, this phenomenon continued through September for both students.

The comments from the tutors in the art school were more positive.

- This tool is able to calculate the number of strokes of each drawing. Students whose numbers of strokes are low, tend to lack detailed observations and draw fewer lines. Therefore, a tutor can easily find students like this, and give concrete advice.
- This is useful as a learning tool because learners can confirm the degree of progress of their drawing. This is also effective as a tool for self-study. Tutors are able to give proper and efficient guidance/advice to learners.

6. CONCLUSION

In this paper, we described the possibility and benefit of a drawing support system in a networked environment. The digital pen has a high potential as a drawing tool. Drawing learning in a networked environment is also useful and available if the users of the system are limited to beginners of drawing. Additionally, we discussed some features of the drawing process and the DPM. Then, its application to the individual learning support system was shown. Also we described the overview of our drawing support system in a networked environment, and then the concept and the functions of the DPM were shown. Its application to classroom learning and individual learning was also considered. Finally, the educational effectiveness of our system was examined. From an experiment with students in an art school, we could see that our drawing learning support system was useful if the users were limited to beginners of drawing.

In future work, we will find adequate drawing tasks to suit the constraints and limitations of the digital pen. During the operation of this system in practice, we try to arrange and revise the DPM and formalize more instructional rules for drawing learners.

REFERENCES

[1] Anoto Group AB : "Digital pen & paper", http://www.anoto.com/the-pen.aspx (2012/05/25 accessed).

[2] Bernstein, N. : "The Co-ordination and Regulation of Movements", Pergamon Press, New York (1967).

[3] Chiueh T. and Deng P. : "Lectern: a digital desk system for video-free course-lecture capturing and playback", IEEE International Conference on Multimedia and Expo, Vol.1, pp.3-6 (2000).

[4] Chuang C.H. : "Integrated Textbook: Augmenting Paper Textbooks with Digital Learning Support Using Digital Pens", IEEE 6th International Conference on Advanced Learning Technologies, pp. 613-617 (2006).

[5] Draw 23 : "Draw Lessons", http://www.draw23.com/ (2012/05/25 accessed).

[6] Drawspace : "Drawing Lessons", http://www. drawspace. com/ (2012/05/25 accessed).

[7] Dykes P.C. and Benoit A., et.al. : "The Feasibility of Digital Pen and Paper Technology for Vital Sign Data Capture in Acute Care Settings", American Medical Informatics Annual Symposium 2006 Proceedings, pp.229-233, 2006.

[8] Ernest W. W.,: "The Art of Pencil Drawing", Watson-Guptill, New York (1985).

[9] Ferraris C., and Martel C. : "Regulation in Groupware: The Example of a Collaborative Drawing Tool for Young Children", Proc. of the 6th Int. Workshop on Groupware, pp.119-127 (2000).

[10] Furukawa K. : "Skill Science", Journal of Japanese Society for Artificial Intelligence, 19(3), pp.355-364 (2004) (in Japanese).

[11] Latash, M. L. : "Progress in Motor Control", Vol.1, Bernstein's Traditions in Movement Studies, Human Kinetics: Urbana, IL (1998).

[12] Latash, M.L. : "Progress in Motor Control", Vol.2, Structure-Function Relation in Voluntary Movement, Human Kinetics: Urbana, IL (2002).

[13] McCullouch, B. and Gunn P. : "Construction Field Data Acquisition with Pen - Based Computers". Journal of Construction Engineering and Management, 119(2), pp.374-384 (1993).

[14] Miura M. : "AirTransNote: augmented classrooms with digital pen devices and RFID tags", IEEE International Workshop on Wireless and Mobile Technologies in Education, pp.56-58 (2005).

[15] Nagai, T., Kayama, M. and Itoh, K. : "A Basic Study on a Drawing-Learning Support System in the Networked Environment", Human-Computer Interaction. Novel Interaction Methods and Techniques, Lecture Notes in Computer Science, Vol. 5611, pp.860-868 (2009).

[16] Nagai, T., Kayama, M. and Itoh, K. : "A Drawing Learning Support System with Auto-evaluating Function Based on the Drawing Process Model", Human-Computer Interaction. Users and Applications, Lecture Notes in Computer Science, Vol. 6764, pp.97-106 (2011).

[17] Open Dictionaly : "Arts; VisualAtrs; Drawing; Education", http://www.dmoz.org/Arts/Visual_Arts/Drawing/ Education/ (2012/05/25 accessed).

[18] Richter K. : "Supervising Knowledge Sharing in the Classroom: Supporting Teachers' Individual Diagnosis and Instruction in a Peer Education Scenario", IEEE 12th International Conference on Advanced Learning Technologies, pp.503 - 505 (2012).

[19] Sato K. : "Developmental Trial in Drawing Instruction at Art/Design Universities", Shizuoka University of Art and Culture bulletin, 4, pp.153-162 (2004) (in Japanese).

[20] Sekine E. : "A Trial to develop the ART SYSTEM", Art Education, 6, pp.89-100 (1984) (in Japanese).

[21] Takagi S., Matsuda N., Soga M., Taki H., Shima T. and Yashimoto F. : "A learning support system for beginners in pencil drawing", Proc. of the 1st Int. Conf. on Computer Graphics and Interactive Techniques in Australasia and South East Asia, pp.281-282 (2003).

[22] Tweddle L. K. : "Reinventing Papert's Constructionism - Boosting Young Children's Writing Skills with e-Learning Designed for Dyslexics", The Electronic Journal of e-Learning, 6(3), pp. 227-234 (2008).

[23] University of the Arts London : "MA Visual Arts (Digital Arts Online)", http://www.wimbledon.arts.ac.uk/ (2012/05/25 accessed).

[24] Yen P. and Gorman P.N. : "Usability Testing of a Digital Pen and Paper System in Nursing Documentation", American Medical Informatics Annual Symposium 2005 Proceedings, pp.844-848 (2005).