SPECIAL ISSUE ARTICLE

GAN-Based Pencil Drawing Learning System for Art Education on Large-Scale Image Datasets with Learning Analytics

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ABSTRACT
We design a GAN-based pencil drawing learning system for art education on large image datasets to help students study how to draw pencil drawings for images and scenes. The system generates a pencil drawing result for a natural image based on generative adversarial network (GAN). The GAN network is trained on pencil drawing big datasets containing image pairs of natural images and their corresponding pencil drawings. Using the pencil drawing learning system, students can paint pencil drawings whenever they want and for whatever they like by uploading an image of the content they want to draw and getting a pencil drawing example of the uploaded image from the system. With the returned pencil drawing, students will see the pencil drawing effect of natural scenes clearly and realize how to draw the pencil drawing for the natural scene. Besides, with students using the pencil drawing learning system, it will be convenient for teachers assigning homework to students. Teachers can know the learning demands of students by evaluating the hand-in homework and update the content correspondingly. We have conducted two user studies for evaluating the practicality of the system, and the result of the two user studies demonstrated the applicability and practicality of the system.

KEYWORDS
Pencil drawing learning system, GAN, art education, pencil drawing big data, learning analytic.

1. Background and Motivation

Nowadays, high technology is getting to integrate into every aspect of people's lives. The convenience of high technology makes people's lives more convenient. And the rapid development of technology enables people to use various computer applications to aid education, among which the virtual reality and argument reality are popular in the field of education. Detail introductions of medical practices and education with virtual reality and augmented reality can be found in Hsieh and Lee (2018). Besides, researchers have also made studies on how to visualize the data of education for improving the quality of education by using high technologies. For example, Hirano and Hirokawa (2017) visualized electromagnetic waves to improve the efficiency of educa-

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tion, Bean et al. (2001) created web-based visualizations to serve diverse groups of high school science students, upper division engineering undergraduates and graduate business students, and so on.

However, there has been no research aimed at helping the education of pencil drawing by using high technology so far. The traditional procedure of pencil drawing teaching is that the teacher selects and organizes target objects and put them on the table in front of the class, and students draw the pencil image by long time observation about the detail of the object. This manner is quite time consuming and is sensitive to the change of the outside world. Students cannot draw the pencil image after class, because the object placed in front of the class cannot be moved. When students are drawing pencil images of humans, the models are asked to keep still for an even half day, which is very tormenting for models. Besides, even a slight movement of the target will affect the final pencil drawing quality. When the teacher assigns homework for students or students encounter some objects or scenes they are interested in, it is difficult for students to know how to well finish the homework because they have no pencil drawing sample of the homework.

In this paper, we propose to develop a cell phone system named GAN-based pencil drawing learning system for art education to help teachers instruct the students' study of pencil drawing. The system requires its user to upload an image and can automatically output an example pencil drawing of this image for the user. So that the user of the system can get the idea of what the pencil drawing of the image he or she is going to paint for looks like. The inner generator of the system is based on generative adversarial network and learns how to get a pencil drawing by learning from large-scale image datasets which contain image pairs of natural images and corresponding pencil drawings. By analyzing the pencil drawing sample, students can know the structure, the contour and the shade relation of the pencil drawing. Then they can well finish their homework easily. And teachers can master the learning dynamics of the students by correcting the homework they handed in.

The pencil drawing stylization algorithm of the system uses generative adversarial network (GAN) to generate the pencil drawing result of the input image. The traditional generator network of GAN uses noise data to generate fake images and the discriminator network distinguishes the image generated by the generator network. While, in this paper, the generator network takes the original image as its input and outputs the pencil drawing result. The discriminator network is used to get the gap between the generated pencil drawing and the real pencil drawing. By balancing the error of optimizing the generator network and the discriminator network, we make the GAN network stable and use it to get the final pencil drawing result.

Big data is an extremely important tool by which society is going to advance. In the past, we used to look at small data and think about what it would mean for understanding the world. But now we have a lot more of it, more than we ever could before. Given a large body of data, we can fundamentally do things that we couldn't do when we only have smaller amounts by analyzing the big data using a variety of data analysis tools. In this paper, we use a large image dataset of image pairs containing original natural images and corresponding pencil drawings to train the GAN network. The GAN network leans the mapping relation between an image and its corresponding pencil drawing from the image pairs big dataset. After training, the GAN network can automatically generate pencil drawing result for an input image.

2. Literature Review

In this section, we will talk about the utilization of high technology in education. The review will be presented in three directions. First, we will briefly take a look at the history of using virtual reality to help education. Then we will talk about the visualization of education which also focuses on the benefit of using high technology in education. At last, we will take a short look at the pencil drawing stylization literature, since we develop the GAN-based pencil drawing learning system based on the pencil drawing stylization algorithm.

2.1. Virtual Reality on Education

Along with the advancement of technology, virtual reality, augmented reality and mixed reality have been widely used in our life, such as education. The virtual reality now is ubiquitous in every aspect of our lives, ranging from industry to entertainment. Since it can visualize objects or view places in a special way, virtual reality is widely adopted in education. Kaufmann (2003) briefly summarized the potential and challenges of using collaborative augmented reality in education under the environments of immersive virtual learning. They described Construct3D which is a collaborative AR application aimed for mathematics and geometry education. Pantelidis (2010) listed the studies of virtual reality usage in education and training, discussed the reasons, advantages, and disadvantages of using virtual reality, and presented a model determining the opportune moments of using virtual reality in education or training courses. Izard, Méndez, and Palomera (2017) analyzed the teaching potential of applying virtual reality to human anatomy and developed a virtual reality software to show users different bones and foramina clearly with stereoscopic goggles. Hsieh and Lee (2018) made detail introduction of medical practices and education with virtual reality, augmented reality and mixed reality, aiming to motivate health professionals' interest in using these technologies to improve the medical care quality.

Traditional surgical education requires cadaveric dissection and experienced doctor supervised training, which makes it constrained by the scarcity of cadavers and the lack of surgeons' time. Virtual reality simulation provides standardized surgical training modules where medical students can repeatedly practice in a risk-free environment. Morris et al. (2006) designed a surgeries simulation system to simulate the visual and haptic of bone surgery so that inexperienced doctors can train their surgical skills conveniently. Fang, Wang, Liu, Su, and Yeh (2014) studied and evaluated a three-dimensional, tactile, virtual reality time bone to train the anatomy and surgical skills. Wong et al. (2014) designed a voxel-based multi-core architecture simulator to render haptic and graphics of virtual bone in real-time, which adopted Marching Cubes and Laplacian smoothing. The virtual reality laparoscopic simulation helps the novice assistants quickly learn what and how to do while doctors are doing an operation. Huber, Paschold, Lang, and Kneist (2015) studied the influence of a single session of virtual reality laparoscopic camera training for the camera assistant on the virtual reality laparoscopic team performance and team cooperation in novices. Wijewickrema et al. (2017) designed a cochlear implant surgery training module to train advanced temporal bone procedure.

Falah et al. (2014) developed a virtual reality and 3D visualization system to teach anatomy, which presents the heat in a real-time 3D representation in an interactive virtual reality environment. Yeom, Choi-Lundberg, Fluck, and Sale (2017) realized rotation, touch, and kinesthetic feedback by using the Phantom Omni haptic stylus and display the 3D human anatomical structures' names on a visual display. Thus, they can evaluate factors that affect the acceptance of undergraduate students on computer-aided learning resources. Hsiao, Chen, and Huang (2012) developed an E-cosystems Augmented Reality Learning System (EARLS) which solves the lack of physical exercise problem.

2.2. Visualization on Education

Konecki, LaPierre, and Jervis (2018) presented the challenges of visually impaired s-tudents, discussed and elaborated methods and technologies aimed at helping visually impaired students in data visualization. Ssimoňák (2016) compared their algorithm visualization results with standard ways of teaching algorithms and data structures to illustrates the effectiveness of algorithm visualization and discussed the future directions for algorithm visualization in computer science education. Silius, Tervakari, and Kailanto (2013) discovered that social network analytic and visualization can help improve the pedagogical practices of online courses, the students' general engagement in study and study live by providing information. Xiaoying, Feng, and Wei (2011) developed a visualization cluster solution for virtual reality education and represented some application results of their virtual reality education platform. Matsutomo, Miyauchi, Noguchi, and Yamashita (2012) designed a real-time visualization to illustrate the magnetic field, which visualizes a composite image of source materials and their generated magnetic field by using the augmented reality technique.

To help programmers read the source code of a java program, Kita, Katayama, and Tomita (2007) designed an automatic visualization tool "PGT(Patch Generation Tool)" for generating paths from a source code via visualizing the corresponding paths of the source code's statements, which makes the understanding of the program easily. J. Lu (2012) designed a high-performance computation and interactive visualization (HPCIV) system for engineering education. The system can concurrently analyze engineering problems with multiple users at different locations via networks. To improve the efficiency of education, Hirano and Hirokawa (2017) proposed to visualize electromagnetic waves, with which students can have a clear understanding of electromagnetic phenomena via changing parameters. Izatt, Scholberg, and Kopper (2014) developed a visualization and data interaction virtual reality application Neutrino-KAVE, which uses a to-scale representation of the Super-K or Hyper-K detector to show the collocation of photon sensors and corresponding color-coded data. Besides, the application visualizes neutrino interaction patterns in a new technique. Nasir, Sheharyar, Shakir, Qaraqe, and Bouhali (2014) illustrated the importance of 3D visualization for engineering students and helped elucidate the intricate and challenging scientific engineering concepts. What's more, they performed a useful case study to visualize the influence of RF signals on the human head and brain.

Yin and Li (2012) designed a web service system to explore the contents of the KEGG (Kyoto Encyclopedia of Genes and Genomes) database with an intuitive and interactive manner. By transforming the two-dimensional KEGG pathways into three-dimensional format, the readability of entries and annotations is improved. Based on microelectronics and its underlying science, Bean et al. (2001) conducted a project to create web-based visualizations. The proposed visualizations aim to serve diverse groups of high school science students, upper division engineering undergraduates and graduate business students. Matsumura, Daisukey, and He (2009) displayed the change of program status during each step, for example, variable value, in a graphical way to help beginners learn the C language via an interesting and comprehensible way. Based on an up-to-date theoretical framework, Pinto, Raposo, and Ramos (2012) reviewed and analyzed some higher education institution information visualization online tools. They concluded some final thoughts of what is driving, work, and outcomes in the particular context of use.

Chu, Hwang, Tsai, and Chen (2009) proposed an intelligent blog system to assist teachers in conducting group learning activities on the Internet, which solved the critical and challenging issue of Web 2.0-based learning, namely the lack of mechanisms for promoting information exchanges and sharing among participating students. Hung, Chao, Lee, and Chen (2013) designed a robot teaching assistant (RTA) to enhance and sustain learning motivation for the learning of English reading skills. Wu, Wang, and Chen (2015) presented a design for a cutting-edge English program which makes elementary school learners in Taiwan who take English as a foreign language lively interact with a teaching assistant robot. Y. Wang and Chen (2012) examined the degrees of collaborative language learning that were supported in cyber face-to-face interaction. The concept of "cyber face-to-face is used to encapsulate the kind of environment where a combination of real-time oral/aural, visual, and text-based interaction happens simultaneously via the various features in an advanced Synchronous Learning Management System (SLMS).

2.3. Pencil Drawing Stylization

According to our knowledge, there hasn't been work about using high technology to aid pencil drawing education so far. Hence, we are going to briefly review the most related and representative works about pencil drawing generation in the order of the year they were proposed. Praun, Hoppe, Webb, and Finkelstein (2001) presented a system to render non-photo realistic hatching strokes over arbitrary surfaces in real time in 2001. They introduce tonal art maps (TAMs) to leverage current texturing hardware and propose an automatic stroke-placement algorithm to create these TAMs with stroke coherence at different scales and tones. Besides, they develop a multi-texturing algorithm to efficiently render TAMs coherently in both spatial and temporal and integrate these TAMs, lapped textures and curvature-based direction fields into a real-time hatching system. Mao (2001) adopted line integral convolution to automatically generate pencil drawing. According to Mao (2001), the stroke textures of pencil drawings are similar to the flow textures generated with line integral convolution. Li and Huang (2003) proposed to generate a pencil drawing from the digital image by employing feature region geometric information in 2003. These feature geometric attributes are obtained by analyzing the image moment and texture of regions. Zhou and Li (2005) proposed to automatically generate pencil-sketch like drawings from personal photos. Their key contribution is the presentation of a computationally simple algorithm for gradient estimation. Lee, Kwon, and Lee (2006) produced pencil drawing style image of input 3D mesh by a real-time pencil drawing technique in 2006. They imitate trial-and-errors of human in contour drawing and map the oriented textures onto the object surface. Besides, they generate and map pencil textures reflecting properties of graphite pencils and paper to improve their rendering results' quality.

Kang, Lee, and Chui (2007) proposed to automatically generate a high-quality line drawing for photographs. They construct a smooth direction field preserving the flow of salient image features, use flow-guided anisotropic filtering to detect highly coherent lines and suppress noise at the same time. Sun (2007) thought existing LIC based automatic pencil drawing generation method may fail under the case that white noises and texture directions are not consistent with the texture structure of input image, so they design a more accurate and rapid graph-based image segmentation approach and a new region-based white noise and texture direction producing method. Z. Chen, Zhou, Gao, Li, and Liu (2008) utilized the superposition of the edge, the Unsharp Mask and image texture to generate pencil drawing for the input digital image. Gao, Zhou, Chen, and Chen (2010) put forward a novel method for automatically generating pencil sketch from a real 2D color image. They use the Sobel operator to detect edges, sharp the input image by Unsharp Mask. Then they apply Line Integral Convolution (LIC) together with color scaling and white noise image, to render pencil sketch with better effects. Ever since 2011, plenty of works of pencil drawing stylization based on previous works have been proposed. N. Wang and Hu (2011) designed an interactive system "IdiotPencil", which can enable users to design pencil drawings directly from the 3D polygonal model. They first estimate feature and hatching path, then generate and render stroke. Users can specify hatching carriers from their experiences or intentions.

Yang, Kwon, and Min (2012) developed a swing bilateral LIC filter to control pencil drawing effects and remedy problems of existing convolution-based schemes. They also sample colors from real color pencils for producing colors of pencil drawings and increase details of drawing to mimic artistic technique in a progressive manner. C. Lu, Xu, and Jia (2012) designed a two-stage pencil drawing system which creatively combines both stroke and tone drawing. They first put stroke generation into convolution framework to capture essential characteristics of pencil sketch and simulate the movement of a pencil while drawing, then use parametric histogram models to adjust the tone so that they can avoid artifacts caused by hatching. They also advocate an exponential model with global optimization to adjust tone, which greatly benefits the rendering procedure of heavily textured regions and object contours. Hata, Toyoura, and Mao (2012, 2013) automatically converted an image into a pencil drawing with accentuation effect that directs viewers' attention to important information, which is realized by utilizing the saliency map. They also propose a novel detail controlling algorithm to locally adapting rendering parameters by a multi-resolution pyramid.

Zhang, Wang, and Xu (2017) proposed an automatic sketch-like pencil drawing generating scheme. Their scheme simulates object contour drawn by artists by extracting line segments with different resolutions, generates pencil texture inappropriate tone and direction with an extended ETF direction field and a parameterized swing bilateral LIC filter, and simulates the physical effect of pencil drawn on paper to transfer pencil texture. Okawa, Yoshida, and Iiguni (2017) automatically converted 2D raster images to sketch style by extracting edges at different resolutions, adding fluctuation of brightness and merging them. They adopt several patterns to distort edges of input images, combine distorted edges with the brightness that has been added fluctuation, then apply pencil texture to the image generated from the above operation. And Q. Chen, Xu, and Koltun (2017) proposed to use a fully convolutional network to accelerate a wide variety of image processing operators including pencil drawing.

Besides, we have published a work focusing on how to maintain the underline structure of the original digital image while converting it into the pencil drawing style (Z. Chen, Jin, Sheng, Li, & Sun, 2018) this year early.

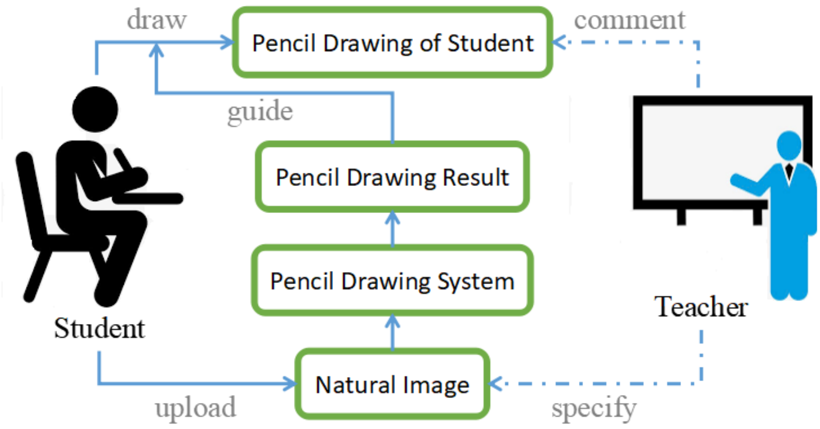

Figure 1. Implementation of the proposed GAN-based pencil drawing learning system. First, students upload a natural image they want to draw or teachers specify a natural image they want students to draw. Then the proposed GAN-based pencil drawing learning system outputs the corresponding pencil drawing result, under the guidance of which students draw their own pencil drawing. At last, teachers make comments on the pencil drawing result of students and give some advice to students for improving the quality of their pencil drawing.

3. Framework of GAN-Based Pencil Drawing Learning System

Using the GAN-based pencil drawing learning system to aid the pencil drawing education procedure requires students to install the system on their mobile phones. Then students can get the example pencil drawing of an image from the system by uploading the image to our system. The image can be specified by their teachers or just what they are interested in. By the guidance of the example pencil drawing from the proposed system, students can know exactly what the pencil drawing they are going to draw looks like during drawing. The next time they are attending the fundamental pencil drawing class, they can give their paintings to their teachers, then their teachers can give advices on their paintings for improving their pencil drawing skill by analyzing these painting works and can update the teaching contents according to the problems exposed by these works. Besides the student can also ask their teachers questions about pencil drawing that they have encountered when they were drawing for images they are interested in or their homework.

Figure 1 shows the implementation of the proposed GAN-based pencil drawing learning system. By correcting paintings handed in by students, teachers can know the students' painting level and make suggestions on problems exposed by the students' paintings. Following the teachers' advice, students can correct their problem in the next drawing process. Under the dual guidance of the developed GAN-based pencil drawing learning system and the teacher, students can improve their ability of pencil drawing rapidly and significantly.

We show the pencil drawing of two freshmen of art school, who knew little about pencil drawing and had certain pencil drawing basis but were not skilled at pencil drawing, before and after using the proposed GAN-based pencil drawing learning system in Figure 3 and Figure 4. The first column of Figure 3 is selected by student A and the first column of Figure 4 is specified by their teacher. The second column of Figure 3 and Figure 4 are the corresponding pencil drawing result of Figure 3(a) and Figure 4(b) generated by the proposed GAN-based pencil drawing learning system. The two students have drawn the pencil drawing of Figure 3(a) and Figure 4(a) before using the proposed GAN-based pencil drawing learning system (see Figure 3(c)

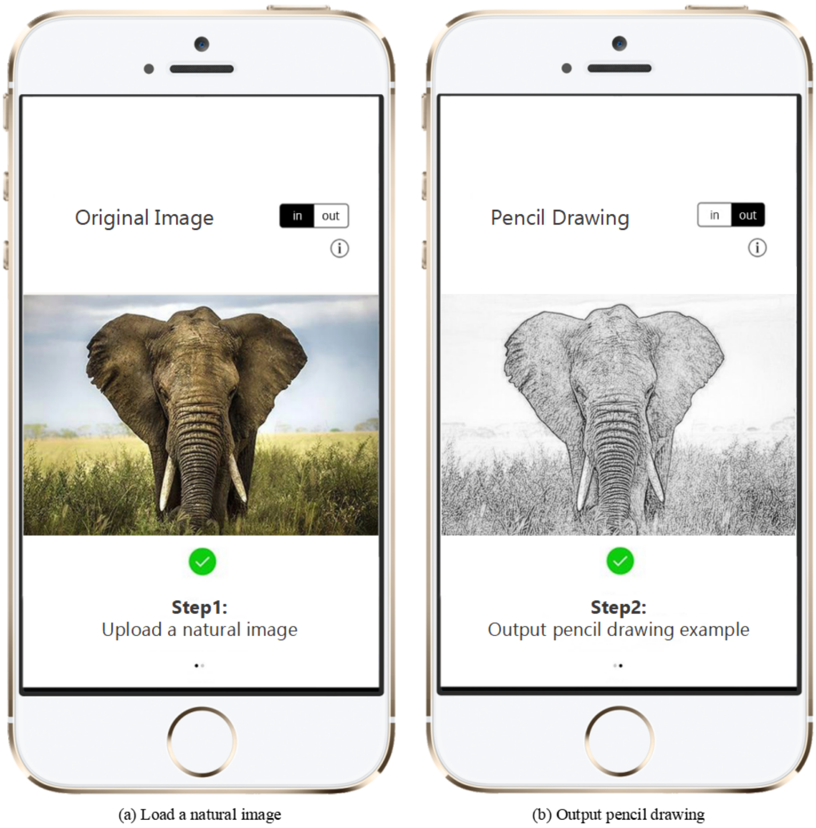

Figure 2. Illustration of the proposed GAN-based pencil drawing learning system. There are two steps in total. First, users of the system are asked to upload an input image, then the system outputs the pencil drawing example image of the input image after pencil drawing style transferring. The specific pencil drawing style conversion process is encapsulated which is invisible to the user of the system.

and Figure 4(c)). After using the proposed GAN-based pencil drawing learning system, the two students also drew new pencil drawing Figure 3(d) and Figure 4(d) of Figure 3(a) and Figure 4(a) by observing the original images and the system pencil drawing outputs. By comprising the pencil drawing results of students before and after using the proposed system, we can see the quality of the two students' pencil drawings has remarkably improved.

3.1. Interface of GAN-Based Pencil Drawing Learning System

Teachers usually lay objects on the table in front of the classroom and ask students to draw a pencil drawing of what they see. This manner is the traditional pencil drawing teaching way and is constrained by the place and time. Students have to draw only in the classroom because they cannot copy the placement of objects their teachers have placed in the classroom accurately. Moreover, this traditional manner is feasible for only some simple objects. When it comes to some complex scene, it is hard for teachers to relive the scene. However, it is boring to drawing simple objects like cube, cuboid and other simple static objects for days and months. Sometimes, teachers may hire some mannequin to sit or stand for hours or even days, so that students can draw some human pencil drawing by observing these models. It is a quite tough experience for these human models before students finishing their drawing.

To help the teaching procedure of pencil drawing, we designed a system which can automatically convert a natural image into pencil drawing style. Our GAN-based pencil drawing learning system contains two main steps. First, students have to upload an image to our system, for which they will draw the pencil drawing. The uploaded image can be specified by their teacher as their homework or can be any image they are interested in. Then the proposed system outputs a pencil drawing example result after a series of processing which is invisible for users of the system. With the output example result of the proposed system, students can mimic or learn the characteristic of the result and draw the pencil image of the input image. It has to be mentioned that students can draw whenever and whatever they want by using the GAN-based pencil drawing learning system. What's more, it will also be convenient for teachers to assign homework to students by specifying an image. The illustration of our GAN-based pencil drawing learning system is shown as Figure 2. By observing the pencil drawing of the system, students can know exactly what it looks like for the pencil drawing of the input image. Besides, the GAN-based pencil drawing learning system allows students zoom the output example pencil drawing to see some details of the pencil drawing so that details of the original image can be well maintained in the pencil drawing of students.

3.2. Pencil Drawing Stylization Using GAN

Pencil drawing is a simple yet effective way to depict what people see by clearly presenting details of the scene. However, it is not easy for researchers to convert natural images into pencil drawings. We attempt to automatically generate a pencil drawing from an input image by using the gated generative adversarial network (GAN) (X. Chen, Xu, Yang, Song, & Tao, 2019). Given a big dataset containing images pairs of original natural images and their corresponding pencil drawings painted by artists, we randomly select seventy-five percent of the dataset as the training set, twelve point five percent of the dataset as the test set, and twelve point five percent of the dataset as the validation set. The training set is used to train the parameters of the generative adversarial network, the test set is to test the accuracy of the parameters trained by the training set, and the validation set is used to further make the parameters solid. We take the natural image set as the input images and the corresponding pencil drawing as the target result. We aim to train a generative network for generating images in the style of pencil drawing, and simultaneously we train a discriminative network to distinguish the generated pencil drawings from the real pencil drawings of artists. The generative network implicitly learns the pencil drawing style from the adversarial loss which aims to fool the discriminator.

4. Research Methodology

4.1. Design

Two classes were invited to help conduct the user study of the GAN-based pencil drawing learning system. One class is asked to use the GAN-based pencil drawing learning system during the whole semester and is asked to do questionnaires before and after the semester. The other class is randomly separated into two groups, and one group is asked to use the system to help the study of pencil drawing while the other group is asked to study pencil drawing without the help of the system. The

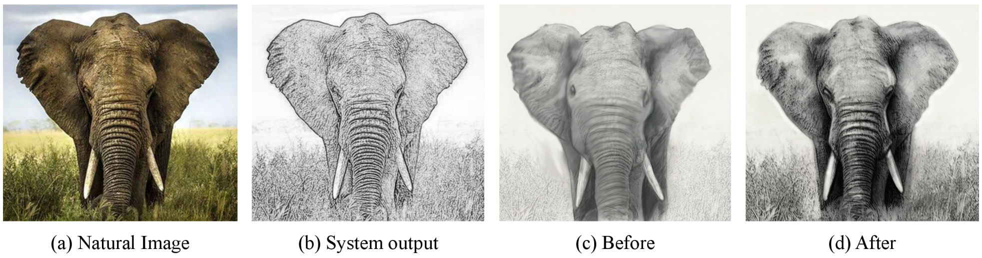

Figure 3. Pencil drawing of student A before and after using the proposed pencil drawing system. (a) is the image which student A is interested in, (b) is the pencil drawing example generated by the GAN-based pencil drawing learning system, (c) is the pencil drawing of student A before using the system, and (d) is the pencil drawing of student A with the help of the GAN-based pencil drawing learning system.

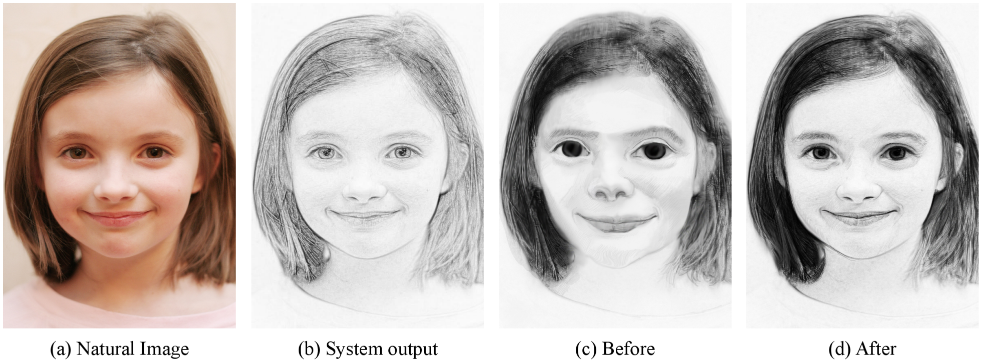

Figure 4. Pencil drawing of student B before and after using the proposed pencil drawing system. (a) is the image that a teacher specified for student B, (b) is the pencil drawing example generated by the GAN-based pencil drawing learning system, (c) is the pencil drawing of student B before using the system, and (d) is the pencil drawing of student B with the help of the GAN-based pencil drawing learning system.

comparison between performance, which is evaluated by scores rated by the teachers, of the two groups during the semester is used to show the effectiveness of using the GAN-based pencil drawing learning system.

4.2. Data

To train the generative adversarial network for automatically generating pencil drawings, we collect an image pairs dataset which contains the original images and their corresponding pencil drawings. We hire 100 pencil drawing artists to draw pencil drawings for 2000 natural images. Each pencil drawing artist is assigned 20 different images. After collecting the 2000 pencil drawing painted by these pencil drawing artists, we get a dataset containing 2000 images pairs of natural images and pencil drawings. Then we randomly select 1500 image pairs as the training set of the generative adversarial network, 250 image pairs as the test set of the generative adversarial network, and 250 image pairs as the validation set of the generative adversarial network.

4.3. Participants

We invited totally sixty first-year university students and six teachers to participate in the user study. These students are from two freshmen classes of fundamental pencil drawing in the Faculty of Humanities and Arts at Macau University of Science and

Table 1. Questionnaire toward the teacher.

Q1. What do you think of your class students' pencil drawing level?				
None(1)	a little(2)	normal(3)	quite good(4)	very good(5)
Q2. What do you think of your class students' interest in pencil drawing?				
None(1)	low(2)	normal(3)	quite high(4)	very high(5)
Q3. What do you think of the students' enthusiasm in class?				
No(1)	less(2)	normal(3)	quite high(4)	very positive(5)
Q4. What do you think of your teaching pressure?				
None(1)	a little(2)	normal(3)	quite heavy(4)	very heavy(5)
Q5. Do you think the proposed GAN-based pencil drawing learning system is useful?				
No(1)	maybe not(2)	a bit of useful(3)	useful(4)	very useful(5)
Q6. Are you willing to use the proposed GAN-based pencil drawing learning system for assisting your teaching?				
No(1)	a little(2)	a little willingness(3)	willing(4)	very willing(5)

Table 2. Questionnaire toward the student.

Q1. How much do you know about pencil drawing?				
None(1)	a little(2)	normal(3)	quite a lot(4)	very much(5)
Q2. What is your current pencil drawing level?				
None(1)	low(2)	normal(3)	quite high(4)	very high(5)
Q3. How are you interested in pencil drawing?				
No(1)	less(2)	normal(3)	a little interested(4)	very interested(5)
Q4. Do you think the system is helpful to you?				
No(1)	maybe not(2)	a bit of useful(3)	useful(4)	very useful(5)
Q5. Are you willing to spend time on pencil drawing after class?				
No(1)	a little(2)	a little willingness(3)	willing(4)	very willing(5)
Q6. What do you think of your enthusiasm in class?				
No(1)	less(2)	normal(3)	quite high(4)	very positive(5)

Technology. There are thirty students per class. We call the first class as CA and the second class as CB. To ensure the fairness of the results for the two class, the teachers of the two classes are the same. Students of CB were randomly separated into two groups A and B. Students of CA and students of group A in class CB were asked to use the GAN-based pencil drawing learning system during their study of pencil drawing, while students of group B were not asked to use the GAN-based pencil drawing learning system.

4.4. Procedure

For the class CA, we asked each student to install the designed GAN-based pencil drawing learning system on their cell phone and complete the fundamental of pencil drawing course with the help of the system. Before and after the semester began, we conducted questionnaire surveys of students and their teachers. The questionnaires for the teacher and the student are shown as Table 1 and Table 2 respectively. We excluded from the analysis of one student who did not return the individual questionnaire and two students who returned the individual questionnaire after a long delay.

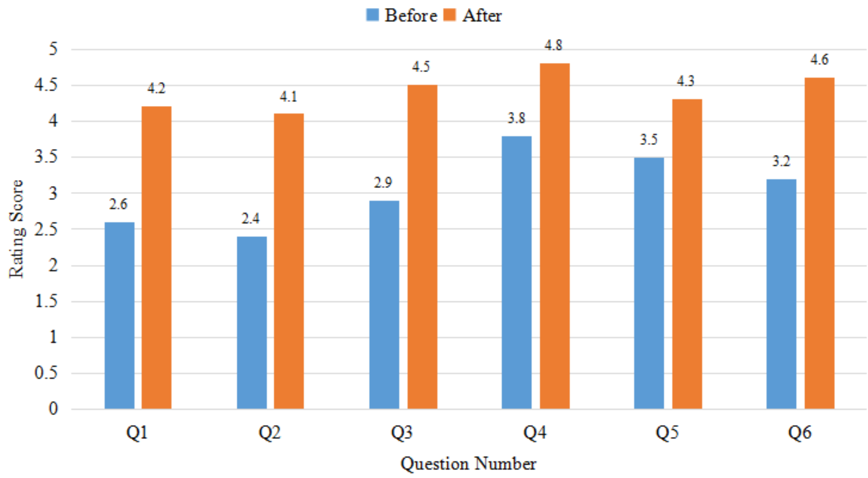

Figure 5. Average answer score for Table 2 of the students for class CA before and after the semester began, which means the average answer score of the questionnaire on students before and after they use the GAN-based pencil drawing learning system. The comparison shows that students think the pencil drawing helped them a lot in pencil drawing and they are happy to use the system in the future.

For the class CB, we randomly separated the thirty students into two groups, namely group A and group B. The students in group A were asked to install the GAN-based pencil drawing learning system on their cell phone and finish the fundamental of pencil drawing course under the co help of the system and the teacher, while the students of group B finished the fundamental pencil drawing course with the help of the teacher and without the help of the GAN-based pencil drawing learning system. At each Friday in the semester, the teacher specified a natural image to the student and asked the students of the two groups to draw a pencil drawing. Students were expected to turn in their homework on Monday of the next week. Then the teacher would score the students' homework to evaluate the pencil drawing skill level for students.

5. Results and Discussions

We recorded the performance of the two classes during the whole semester and analyzed the influence of our proposed GAN-based pencil drawing learning system over students' pencil drawing education. Details can be seen in the following subsections.

5.1. Analysis of Class CA

The average score for each question in the questionnaire answered by the thirty first-year students in the first class CA is shown in Figure 5, and the average score for each question in the questionnaire answered by the six teachers for the first class CA is shown in Figure 6. From Figure 5, we can see that the students of class CA think the GAN-based pencil drawing learning system is useful for them, and their passion for pencil drawing and enthusiasm in the class have been greatly stimulated. From Figure 6, we can conclude that the teachers feel that the GAN-based pencil drawing learning system help motivated the students' interest in pencil drawing and think that the pencil drawing skill of the students in class CA has been improved under the help of the system. They are very happy to continue using the GAN-based pencil

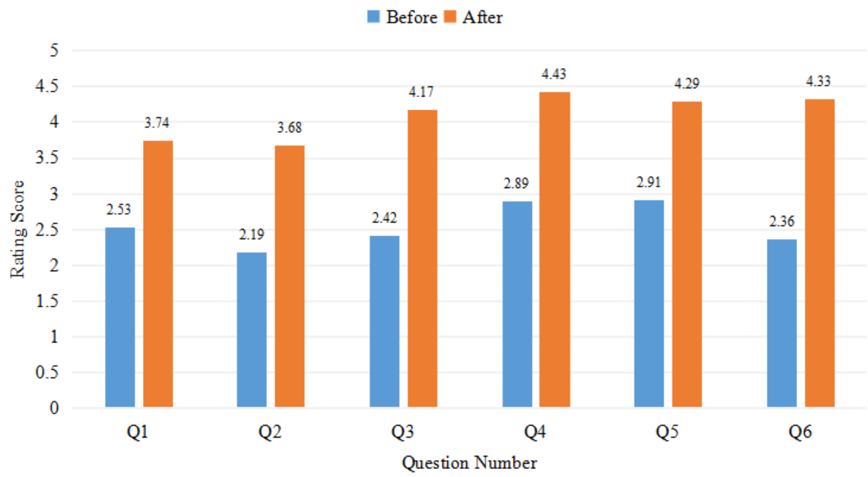

Figure 6. Average answer score for Table 1 of the teachers for class CA before and after the semester began, which means the average answer score of the questionnaire on teachers before and after students in class A using the GAN-based pencil drawing learning system. The comparison shows that teachers think the GAN-based pencil drawing learning system is helpful and they are willing to use the system for aiding them to teach students.

drawing learning system to aid them in teaching their future students. All in all, the comparison between the average rating scores of the students and teachers in class CA before and after the semester in Figure 5 and Figure 6 showed that the GAN-based pencil drawing learning system indeed helped students learn pencil drawing.

5.2. Analysis of Class CB

We recorded the score marked by the teachers for each student in both groups of each week. The record results are showed in Table 3, from the row of which we can see the pencil drawing skill of all students were getting better as time went on. It has to be mentioned that in Table 3, w1 denotes the first week in the semester, w2 denotes the second week and so on. a* and b* are students' ID to identify students in the two groups A and B separately.

Table 4 shows the mean score and standard deviation of the two groups at each week. It can be seen from Table 4 that the pencil drawing skill of students in both groups are getting better. But the level of students' pencil drawing in group A improved faster than those in group B, which demonstrated the GAN-based pencil drawing learning system had played a positive role in the pencil drawing study procedure of group A. The average score and the standard deviation of the scoring record for each student in the whole semester are shown in Table 5, from which we can see that the overall pencil drawing skill of group A is better than that of group B.

We also show the mean score of the two groups at each week in Figure 7 and the average score of the scoring record for each student during the whole semester in Figure 8. The curve trend in Figure 7 and Figure 8 showed that the pencil drawing skill of students in both groups A and B improved with time, and the curve relation of group A and B demonstrated that with the help of the GAN-based pencil drawing learning system, the overall performance of students in group A is better than that of students in group B.

Table 3. The record of score rated by the teacher for each student in group A and B of class CB at each week of the semester. w* is the week number of each week, and a*,b* is the student ID for group A and B.

Group A														
	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14
a1	52.6	54.5	59.6	60.5	63.7	70.7	76.8	82.6	82.8	89.4	93.6	95.3	98.6	100
a2	51.8	52.1	58.4	59.9	61.0	61.5	64.7	67.8	69.9	70.8	71.6	76.7	79.9	97.2
a3	67.5	72.3	73.5	76.1	82.9	83.6	86.1	86.5	86.5	88.2	92.2	95.2	95.4	97.5
a4	59.3	60.0	65.2	66.7	67.0	68.9	71.3	73.9	75.9	76.5	79.5	80.0	83.4	99.4
a5	52.3	53.6	55.6	58.5	63.4	64.0	64.1	70.0	71.2	76.6	78.4	78.6	80.9	97.6
a6	50.6	52.2	54.6	58.4	61.8	68.8	68.9	73.4	76.5	82.3	87.6	89.5	94.4	98.1
a7	52.5	59.1	59.8	61.8	67.5	69.0	69.1	69.8	76.8	78.1	79.9	83.1	95.6	96.5
a8	52.0	54.6	55.9	59.7	76.8	78.5	80.1	90.0	90.4	94.5	95.1	95.5	96.7	99.5
a9	58.0	61.6	62.8	62.9	65.4	77.0	79.0	79.5	80.1	81.0	83.3	85.7	86.3	95.0
a10	50.6	61.1	69.0	70.2	74.8	75.7	82.9	84.0	84.9	87.5	87.8	90.2	92.7	94.7
a11	53.2	58.6	61.2	61.8	64.6	68.8	69.3	69.7	70.9	77.6	86.5	92.0	97.4	97.9
a12	56.8	64.0	64.8	64.8	65.0	67.6	68.3	74.1	80.7	81.6	85.2	89.6	91.4	96.6
a13	54.0	55.3	58.9	60.8	63.8	64.4	66.1	66.2	68.6	72.9	78.4	80.8	81.6	92.9
a14	53.2	55.4	63.0	70.8	75.9	76.0	76.9	81.3	83.5	86.9	91.2	94.1	96.8	100.0
a15	52.8	55.7	60.2	61.4	68.9	69.9	70.0	72.6	84.3	87.1	87.8	93.4	94.3	97.9
Group B														
	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14
b1	50.5	51.0	52.9	53.7	57.0	62.9	67.9	73.2	73.9	79.9	83.7	84.8	87.5	89.3
b2	50.8	50.9	51.9	53.5	53.9	54.1	57.8	60.7	62.3	63.1	64.0	68.5	71.2	86.1
b3	60.3	64.2	65.0	68.1	73.8	74.7	76.6	76.9	77.1	78.1	82.1	84.5	85.3	87.2
b4	52.9	53.1	58.2	59.4	59.5	61.1	63.0	65.6	67.2	68.3	70.7	71.0	74.2	88.6
b5	50.1	50.4	50.4	51.9	56.6	56.9	57.3	62.2	63.2	68.2	69.8	70.0	72.4	87.1
b6	50.8	50.8	50.9	52.0	55.2	60.9	61.0	64.9	67.6	73.0	78.2	79.3	83.7	87.6
b7	50.7	52.6	53.1	55.0	59.9	61.5	61.7	62.1	68.7	69.4	71.3	74.3	84.7	86.3
b8	50.3	50.6	50.9	53.1	67.8	69.8	71.5	80.2	81.0	83.8	84.6	84.8	86.0	88.5
b9	51.7	54.9	55.6	55.7	58.4	68.0	70.5	70.8	71.3	72.4	74.0	76.5	76.6	84.5
b10	50.9	53.9	61.8	62.1	66.9	67.1	74.0	74.7	75.8	77.5	78.5	80.3	82.9	84.7
b11	50.3	52.1	54.2	54.5	57.1	61.6	61.6	61.8	62.9	68.5	77.3	81.8	86.5	87.7
b12	50.9	57.0	57.4	57.4	57.7	60.1	60.6	66.2	71.4	72.7	75.9	79.8	81.4	86.5
b13	50.4	50.8	51.8	54.2	56.4	57.3	58.5	59.3	61.1	64.8	69.3	72.1	72.4	82.5
b14	50.6	50.7	56.0	62.7	67.6	67.9	68.3	72.3	74.2	77.4	80.8	84.0	86.1	88.7
b15	50.1	50.9	53.4	54.9	61.6	62.3	62.5	64.5	74.7	77.6	77.7	82.9	83.6	87.4

Table 4. The average score and standard deviation of the score record at each week for each group. The average pencil drawing skill of group A are always better than those of group B.

	A_mean	B_mean	A_std	B_std		A_mean	B_mean	A_std	B_std
w1	54.5	51.4	4.3	2.5	w8	76.1	67.7	7.1	6.3
w2	58.0	52.9	5.2	3.5	w9	78.9	70.2	6.5	5.9
w3	61.5	54.9	4.9	4.1	w10	82.1	73	6.5	5.7
w4	63.6	56.5	5.0	4.5	w11	85.2	75.9	6.4	5.7
w5	68.2	60.6	6.2	5.6	w12	88.0	78.3	6.4	5.6
w6	71.0	63.1	5.8	5.3	w13	91.0	81.0	6.5	5.7
w7	72.9	64.9	6.6	5.9	w14	97.4	86.8	2.0	1.8

Table 5. The average score and standard deviation of the score record for each student. The pencil drawing skill of students in group A are better than those in group B.

	A_mean	B_mean	A_std	B_std		A_mean	B_mean	A_std	B_std
s1	77.2	69.2	16.3	13.9	s9	75.5	67.2	10.9	9.7
s2	67.4	60.6	11.5	9.5	s10	79.0	70.8	12.3	10.2
s3	84.5	75.3	8.9	8.0	s11	73.5	70.8	14.0	12.3
s4	73.4	65.2	10.1	9.0	s12	75.0	66.8	11.9	10.7
s5	68.9	61.9	12.2	10.3	s13	68.9	61.5	10.8	9.2
s6	72.6	65.4	15.4	12.6	s14	78.9	70.5	14.1	12.0
s7	72.8	65.1	12.6	10.9	s15	75.4	67.4	14.6	12.5
s8	80.0	71.6	16.9	14.2					

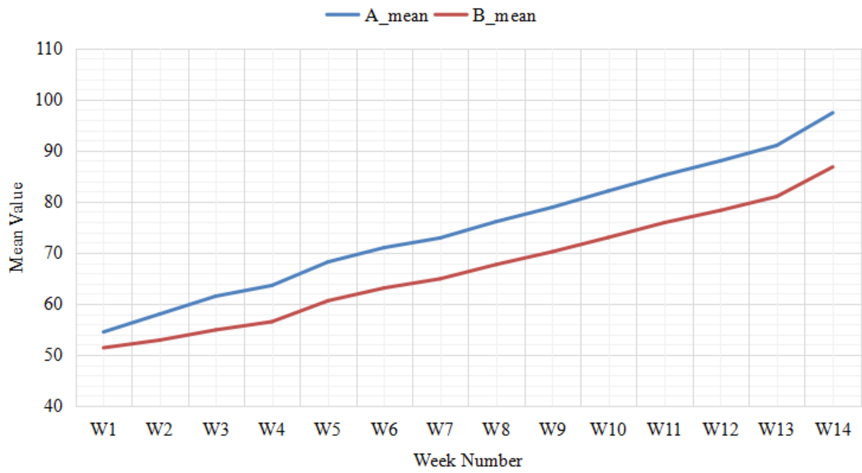

Figure 7. The average score and standard deviation of the score record at each week for each group. Then pencil drawing skill of students in both groups A and B are getting better with time. The pencil drawing skill of students in group A is always better than that in group B at each week.

5.3. Subtasks Performance Analysis of Class CB

The procedure of people drawing a pencil image can be divided into five sub-steps: drawing the overall ratio, drawing the whole contour, drawing coarse lines, drawing details, and drawing shades. Thus, we also asked students of class CB to record the time they cost to finish each subtask and how difficult they thought about these subtasks when they were finishing their homework assigned by their teachers. We collected their records and analyzed these records of each week when they handed in their homework to their teachers. The average completing time and difficulty level of each subtask of each week were shown in Table 6. For simplify, we denote drawing ration as Dr, drawing contour as Dc, drawing coarse lines as Dcl, drawing details as Dd, and drawing shade as Ds.

It is hard to properly set the ration of objects in the scene. When properly found the ratio, it is easy to draw the contour and coarse lines. But, the details and shade are crucial for a pencil drawing which means that it is also difficult to draw the details and shade of a pencil drawing. As we mentioned before, there are two groups in class CB: students of group A studied pencil drawing with the co-guidance of teachers and the GAN-based pencil drawing education system, while students of group B studied pencil drawing only with the guidance of teachers. Thus, we recorded the completing time and difficulty level of each subtask into two groups (details can be seen in Table 6).

Both records of group A and group B in Table 6 show that the Ds, Dd and Dr subtasks are harder than the Dc and Dcl subtasks. As the learning progresses, students' pencil drawing skills become more and more mature, which can be seen from the decreasing completing time and the difficulty level of each subtask. Besides, we can see from Table 6 that it cost fewer time for students of group A to finish each subtask than students of group B and the subtasks were easier for students of group A than students of group B, which illustrated that the proposed GAN-based pencil drawing education system can indeed help students understand the image structure and decide how to draw the pencil drawing result of the original image better.

Table 6. The average completing time and difficulty level of subtasks for group A and B of class CB at each week through the semester. Dr: Drawing ration. Dc: Drawing contour. Dcl: Drawing coarse lines. Dd: Drawing details. Ds: Drawing shade. w* is the week number of each week. CT: Completing Time (hour). DL: Difficulty Level (1-10).

		Dr		Dc		Dcl		Dd		Ds	
		A	B	A	B	A	B	A	B	A	B
w1	CT	2.88	3.28	1.86	2.27	0.92	1.41	3.82	4.32	4.98	5.19
	DL	5.98	6.25	3.95	4.31	1.97	2.38	7.97	8.40	9.96	9.98
w2	CT	2.87	3.26	1.80	2.20	0.91	1.20	3.76	4.12	4.98	5.13
	DL	5.96	6.16	3.94	4.10	1.95	2.23	7.91	8.37	9.82	9.93
w3	CT	2.84	3.24	1.79	1.98	0.89	1.17	3.63	4.04	4.98	5.13
	DL	5.86	6.06	3.89	4.09	1.95	2.22	7.72	8.17	9.72	9.74
w4	CT	2.79	3.06	1.71	1.95	0.89	1.15	3.62	4.03	4.77	5.06
	DL	5.85	6.02	3.85	4.08	1.90	2.19	7.62	7.96	9.64	9.72
w5	CT	2.76	3.03	1.61	1.92	0.86	1.09	3.57	3.93	4.74	5.05
	DL	5.65	5.98	3.84	4.06	1.84	2.13	7.59	7.92	9.44	9.72
w6	CT	2.75	2.99	1.41	1.86	0.77	1.08	3.55	3.87	4.68	4.90
	DL	5.48	5.87	3.72	3.93	1.77	2.12	7.54	7.86	9.42	9.71
w7	CT	2.70	2.90	1.39	1.77	0.74	1.06	3.49	3.71	4.65	4.90
	DL	5.41	5.69	3.63	3.92	1.74	2.11	7.47	7.81	9.39	9.68
w8	CT	2.64	2.83	1.33	1.65	0.74	0.95	3.44	3.59	4.56	4.84
	DL	5.41	5.48	3.61	3.86	1.70	2.02	7.28	7.69	9.36	9.66
w9	CT	2.57	2.76	1.33	1.61	0.73	0.92	3.38	3.58	4.48	4.84
	DL	5.29	5.45	3.55	3.71	1.67	2.01	7.25	7.66	9.35	9.64
w10	CT	2.51	2.73	1.17	1.54	0.65	0.85	3.36	3.57	4.36	4.69
	DL	5.25	5.45	3.55	3.61	1.66	1.97	7.23	7.59	9.33	9.59
w11	CT	2.35	2.71	1.11	1.24	0.61	0.82	3.29	3.56	4.32	4.55
	DL	5.22	5.39	3.47	3.57	1.65	1.93	7.19	7.58	9.29	9.33
w12	CT	2.22	2.67	1.06	1.24	0.58	0.77	3.25	3.51	4.14	4.41
	DL	5.14	5.38	3.33	3.56	1.55	1.93	7.18	7.48	9.15	9.28
w13	CT	2.12	2.49	1.05	1.23	0.56	0.68	3.13	3.41	4.00	4.38
	DL	5.08	5.36	3.32	3.39	1.53	1.91	7.15	7.40	9.10	9.17
w14	CT	2.05	2.48	1.05	1.09	0.52	0.65	3.07	3.34	4.00	4.21
	DL	5.01	5.15	3.10	3.35	1.51	1.53	7.10	7.32	9.04	9.09

6. Conclusion and Future Work

To help teachers teach students pencil drawing, we designed a GAN-based pencil drawing learning system which can get a pencil drawing example of a natural image. Then students can start their pencil drawing creation with the guidance of the pencil drawing example. We have conducted two user study before and after the students using the proposed GAN-based pencil drawing learning system, and the comparison result between these two cases demonstrated the advantage and effectiveness of the proposed GAN-based pencil drawing learning system. The developed GAN-based pencil drawing learning system provides students with the freedom of choosing what they want to draw and when to draw, and the system also greatly promotes the students' interest in pencil drawing.

However, there are some limitations to this study. First, the GAN-based pencil drawing learning system is mainly for the first-year students of art school, who know little about pencil drawing. For those students who are skilled at pencil drawing, the GAN-based pencil drawing learning system may be of little use. Second, since the designed GAN-based pencil drawing learning system just generates a pencil drawing example of the input image and does nothing about analyzing how to draw a pencil drawing, students who have never studied pencil drawing may get nothing useful from our system. Thus, the future work for us will be developing an advanced GAN-based pencil drawing learning system which will illustrate how the pencil drawing of an input image is painted. And the target of our system will try to include high students who may learn pencil drawing during their high school period and enter a university as an art special student by taking the art test before the college entrance examination.

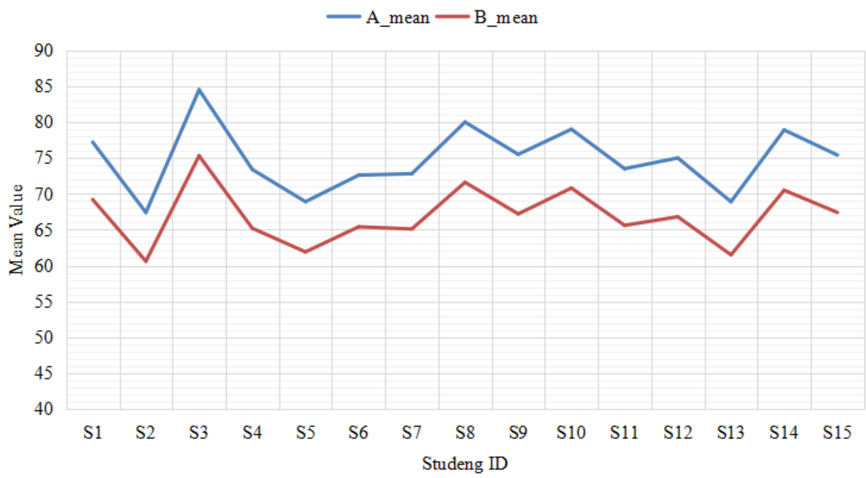

Figure 8. The average score and standard deviation of the score record for each student of the whole semester. All students in group A performs better than students in group B.

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Disclosure statement

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