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Design and Drawing CAD Education with Modeling Technical Assistance – Effective Education Through Self-Assessment and Collaboration

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Abstract. The National University Corporation of Tsukuba University of Technology (NTUT) is the only higher educational institute for the hearing-impaired and visually-impaired in Japan. Mechanical engineering courses teach hearing-impaired students. In the training of Design Drawing CAD, the disabilities of students are considered individually so that students, even with hearing impairment, can understand the basic contents of Mechanical Engineering visually. They are taught to have design sense through experience, learning with frequent utilization of models, which gives the students a realistic effect, thereby bringing about self-assessment. In NTUT, students learn 3D modeling of precision mechanisms. We are using 3D CAD with due consideration of machining accuracy so that models function without any post-machining work. We have been continuing graduate study by students in a course entitled "Manufacturing of Precision Mechanism Model by 3D Printer". Plastic is used as a material in 3D CAD and 3D RP modeling; so the accuracy of machining plastic must be taken into consideration. 3D CAD has been used in preparation of drawings even in the classroom, and now assembly drawings can be created by group work.

In the training of Design Drawing CAD, students are required to learn through experience. And they need to learn that 2D/3D drawing is a language of engineers, a means of communication and a tool for optimization. 3D modeling must be a tool for proper communication. Used with 2D/3D-CAD and 3D modeling, it has spread the possibility of the power of collaboration. We will introduce the new teaching methods through our practice.

Key Words: design and drawing CAD education, hearing impaired, three-dimensional modeling, effective education, self-assessment, collaboration

MSC 2010: 97G80, 68U07

1. Introduction

Students with hearing impairments are studying in mechanical engineering classes at the Department of Industrial Information, the Faculty of Industrial Technology of the National University Corporation of Tsukuba University of Technology (NTUT). Important educational subjects include mechanical design and drawing plus CAD. These are taught as class subjects, as drawing is considered a useful engineer's language as well as a communication tool for students to transfer information. Quite a few graduates have successfully gained employment in a work position in related fields. We have personally been engaged in the education of design and drawing, CAD/CAM and modeling, and involved in the establishment of a study environment as well as the improvement of teaching methods, to attract the interest of students to the subjects and to make them study in earnest. This effort is intended to encourage students to develop their own capabilities using their own initiative, which is also done through educational collaboration with classes at the Tsukuba Gakuin University and the Tokyo City University as well as exchanges with sister universities overseas. Through exchange programs with other universities, students receive positive stimulus by self-assessing their concrete accomplishments such as design drawing and its data, modeling, product, or study results.

Design drawings are used as a communication tool for engineers as well as an instruction for manufacturing. We have been trying to encourage students to acquire a good sense in design and drawing through practical education involving the use of actual design drawings. Students are educated to become engineers who are capable of considering the precise transfer of information through drawing as an engineer's language, so that manufacturing is accurately performed. We have been continuously engaged in the brushing-up of teaching materials and the improvement of teaching methods, as drawing is an important tool of information transfer which is equivalent to the student's language. The education starts from handwritten drawings to the use of 2D CAD, 3D CAD and geometric models produced by 3D printers. Under such guidance, students are not only made to find their own focus points for easy understanding while completing general design samples given as subject tasks, but they are also assigned to additional educational tasks other than those given in the textbook.

In this paper, we give an introduction to the experiences of the NTUT Mechanical Design and Drawing CAD education in which the students themselves evaluate and examine models including their completed forms produced by 3D printer in order to induce their own awareness of studying for optimization and with the desire for self-improvement, under an educational environment in which students can learn through experience and actually touch models produced from drawings and drawing data as an aid in communication.

2. Collaborative education and collaborative work in class

It is necessary for the students to gain an actual sense of the role that drawing plays. We have also introduced an element of collaborative learning while students examine the actual shapes of models produced by 3D modeling in comparison to the drawings in order to evaluate the design and drawing from the shape, function, performance, etc. of the model, so that students with hearing impairments would understand through their own experiences that design drawing needs to contain accurate instructions as well as considerations for machining, as drawing is an engineer's tool for communication and/or information transfer.

Students acquire a good sense in CAD utilization, accomplishing tasks that are given in a way that they can self-assess with satisfaction.

NTUT Collaborative Education has developed through efforts in various collaborations; collaboration with sister schools, associated schools, local communities, and foreign countries. In recent years, students have been creating models by 3D CAD modeling through collaborative work. Instead of individual work, collaborative work was introduced, to create drawings by 2D CAD to allow consideration for the future necessity of the student's collaborative work. In order to recognize the necessity of transferring information with the use of accurate drawings, an effort has been made to encourage students to evaluate through experience the original role of drawing to transfer information under cooperation as a team consisting of designers and manufacturers. Thus, the scope of education has been expanded.

3. Related class subject

Shown below are contents of Collaborative Education regarding CAD education. Among them, Table 1 shows class subjects of which the first-named author is in charge of.

Table 1: Class subject regarding design and drawing CAD education

Subject	*Unit*	*School Year*	*School Term*	*Hour / week*
Exercises in Basic CAD	1	1	2	1
Manufacturing Processes	2	2	2	1
Practice of Manufacturing Processes	4	2	1-2	2
Exercises on Machine Design and Drawing	4	2	1-2	2
Exercise in CAD/CAM	4	3	1-2	2
Final year Project in Systems Engineering	6	4	1-2	–

3.1. Exercises in basic CAD

In the first year of majoring in systems engineering, students who have not yet decided whether they should enter a mechanical or an architectural engineering course are obliged to participate in exercises in basic CAD. Therefore the exercises are programmed so that students, without the knowledge of their future disciplines, can also study CAD. Drawing education is conducted in such a way that students not only learn CAD operation but also acquire a good sense in CAD operation, while they accomplish tasks in manufacturing by cutting various shapes such as regular hexahedrons, regular tetrahedrons, hexagonal cylinders and other solids based on an expansion plan, by making section paper, production of a paper plane, machining of a key holder, 3D modeling of a miniature stamp, etc. Students are guided through the study of basic CAD in collaboration with other people and are able to experience the work of assessment and optimization under collaborative education.

3.2. Manufacturing processes and practice of manufacturing processes

Students need to gain knowledge about machining and machining exercise in the second year as a basis to acquire a good sense in CAD operation through the practice of manufacturing. At the beginning of the machining exercise, students observe and sketch the machine in front of them. The exercise starts with drawing a bolt and a nut. They prepare the drawing while referring to the actual bolt and nut with its drawing. This will be their first experience of

mechanical drawing, although they still need to study Japanese Industrial Standards (JIS) for mechanical drawing and repeat the practice of drawing lines and writing letters.

It is essential that students experience manufacturing through machining exercises to assess the dimensions, shapes, functions and performances of products manufactured through the process of plan-design-draw-manufacture to attain improvement towards optimization. To conduct design and drawing education through manufacturing experience, it is essential to obtain knowledge about various machining processes such as manual finishing, marking, filing, threading, drilling machine, lathe, milling machine, welding, casting, etc. The experience and knowledge gained through these basic machining exercises need to be reflected in design and drawing. The experience of manual machine operation, like turning a handle, is quite useful even for the operation of a computerized machine which automatically decides the operating conditions such as machining direction, machining procedures, machining velocity, cutting depth, etc. to cut and machine a metal cylinder or a block. As all these matters are related with descriptions on drawings, including even that of surface finishing, students need to recognize that drawing is the most important skill in a compilation of studies and exercises. A machining exercise, *"Manufacturing of M12 bolt and nut"*, gives a good opportunity to tell students the above-mentioned matters for the first time.

3.3. Exercises on machine design and drawing

In the class of the Mechanical Engineering course in the second year, students study manual drawing in the first term, and CAD drawing in the second term.

Students study JIS for mechanical engineering, exercise writing letters and drawing lines, and then exercise drawing (first manually, later with 2D CAD) of a V-block, a packing gland, a chuck handle, a carbide center, a snap gauge, a pair of compasses, a lathe dog, an eye bolt, a bolt and nut, a small jack, a spanner, other machine parts, a cone clutch, a shaft coupling, a jack, etc. Besides that, a special effort is made in holding a *"Paper Plane Workshop"* as one of Tsukuba City's public events in which students contribute to society by designing and manufacturing display stalls on which they present their individual design drawings of paper planes. In addition, a *"Paper Car Race"* is held as part of inter-university or international collaborative education in which students compete for race times in different conditions. The students are stimulated by these events and they gain a deeper and wider scope of their study not only through classroom learning but also through exchange with local communities or other local or overseas universities through design, drawing and CAD.

3.4. Exercise in CAD/CAM

In the third year class, students study 3D CAD in the first term. A 3D drawing is created through an input of 3D CAD data using a 2D drawing already produced in the mechanical design and drawing exercise. In this way, a 3D image is recognized not only through the monitor, but also by 3D models produced by a 3D printer so that students can visually find any features which they did not understand up until they complete the 3D drawing. Students will touch the models to confirm the accuracy of their 3D drawings. Models are produced to half-scale, excluding those with complicated shapes, as the materials can be too costly in the case of full-scale mockups. Even though we find students making mistakes during the preparation of their 3D drawings, lecturers do not inform them of any mistakes but wait for the students to become aware of their mistakes through self-assessment. As students have prepared a 2D drawing to know all the details about the drawing, no additional explanation

should be needed for the students, but they still make various kinds of unique mistakes, such as a misunderstanding of shape, a shortage of parts, etc. during the preparation of the 3D drawing.

Modeling gives the actual form to an image, the students have drawn in their minds. So they can enjoy modeling by making use of the models, referring to them to facilitate further detailed study. In the latter half of the first term, students create a 3D assembly drawing based on the drawing sample of a hand-winding winch in the textbook. The work is divided and assigned to groups for group work. The assembling process is made and presented as an animation.

Students study CAM in the second semester. A part-time lecturer dispatched from a company will be in charge of education on the operation of the Machining Center (MC) in the Exercise Shop and he also gives lectures on machining, including those involving air planes in his company; the students listen to his lecture with great interest. In the case of a part-time lecturer invited from outside of NTUT or a newly assigned full-time lecturer, all words spoken by the lecturer are displayed on a screen placed in the classroom. The course of education includes a plant tour, in which students, led by the lecturer in charge, can also see the process to manufacture air planes. A plant tour is the most effective way for students to gain a deeper interest in their studies, as they are stimulated from seeing actual manufacturing sites, and not just pictures or lectures.

3.5. Final year project in systems engineering (graduate study)

In the fourth year, students are regrouped under individual teachers, but all of them spare time to design and draw a hand-winding winch with individual conditions as a design exercise. Students assigned to the first-named author produce 3D models, a named precision device model, by a 3D modeling machine and consider the shape and function of the models (see Figures 1–2).

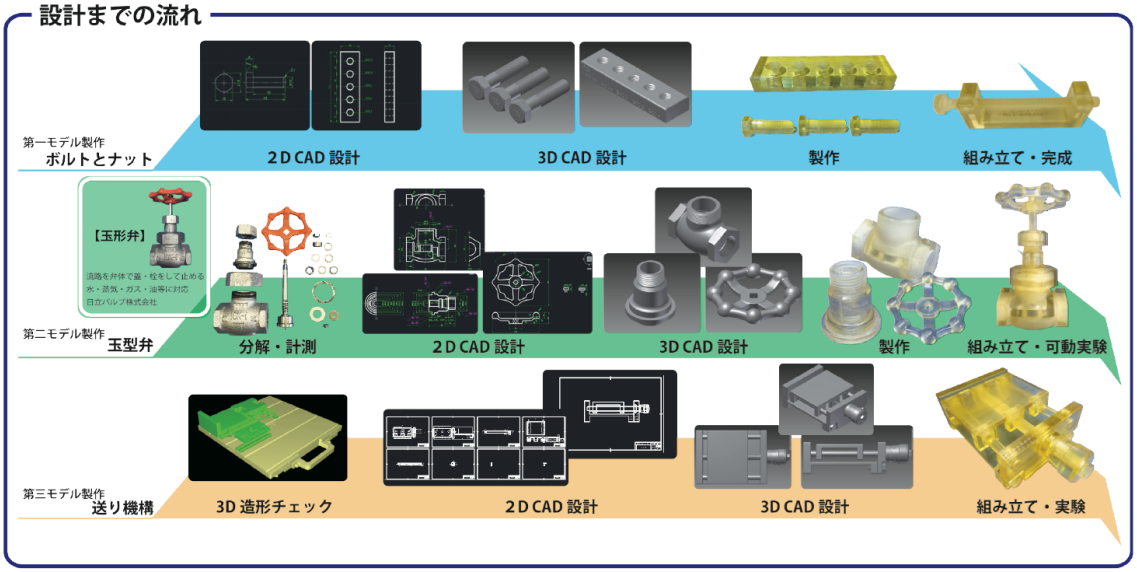


Figure 1: The flow of the design for a precision device model which was produced as a precision 3D mechanism model of a student's work

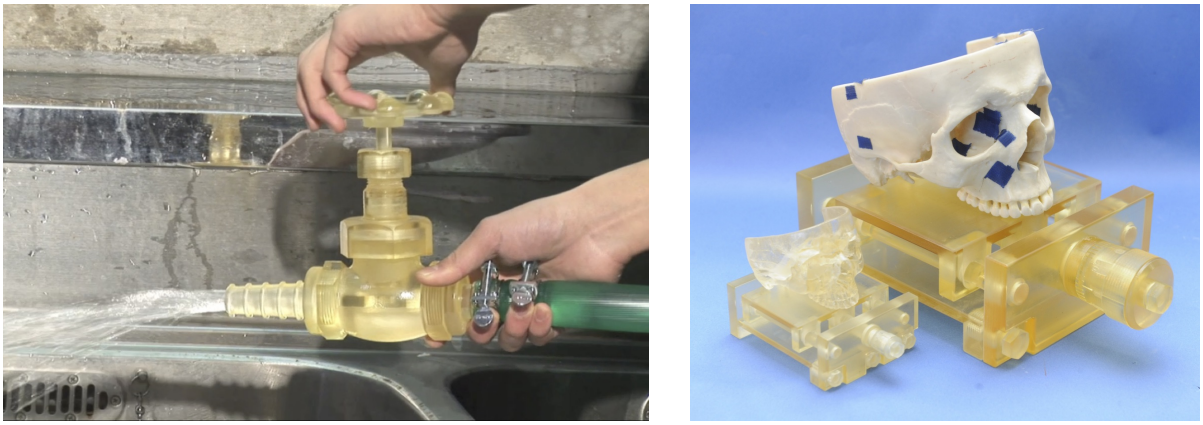


Figure 2: Student made a feed table for CT/MRI scanning machine for 3D measurement using a trapezoidal screw after confirmed by Globe valve's work

4. Practice results and consideration

4.1. Creation of section paper by CAD

The creation of section paper was introduced as one of trial operations of collaborative education in 2D CAD. Before the study of drawing of mechanical elements, the creation of section paper was set as one of optimum subjects to enhance collaboration in CAD education. Students create section paper of the highest possible quality through collaborative work; they are required to achieve the highest quality in the same manner as exercised in the improvement activities by manufacturers. They can experience a sense of accomplishment by succeeding in the creation of a product, exactly like the real section paper, as a result of the repetition of improvement activities. Within a group, students compare with each other the numerical figures of input data for line thickness and the color of their individual products in which line thicknesses are different at an interval of 1 mm, 5 mm, 10 mm and 50 mm. Then, through reflection of the compared results, they repeat the creation of the section paper with revised input data. Through the repetition of such improvement activities, students can achieve the production of an optimum section paper as a group.

To cite an example, a section paper submitted by one group had lines drawn with the thickness of 0.05 mm at intervals of 1 mm, 0.15 at 5, 0.20 at 10, and 0.30 at 50. It greatly differs to mechanical drawings in which a thick line of 0.7 mm and thin line of 0.35 mm are usually have to be used. Students revise the line thickness and color freely, and repeat the process of evaluation, consideration and discussion in order to proceed with optimization towards the making of a section paper fit for commercial use. As the quality of the product also depends on the characteristics of the used printer, CAD input data are decided after confirming the best state of printer output through the process of trial and error. The input data also reflect the group's preference.

In this practical exercise, students use CAD as one of the useful tools to produce section paper, and repeat the evaluation of the revised products together with their group members to achieve optimization. Students enjoy reliable communication, as they can discuss anything specifically referring to numerical data. Therefore, it can be said that this collaborative work to produce section paper has something qualitatively different from simple imitation. Through this practice, students raise the quality up to a level of satisfaction and then proceed on with the optimization in order to create products which are better than those that are commercially

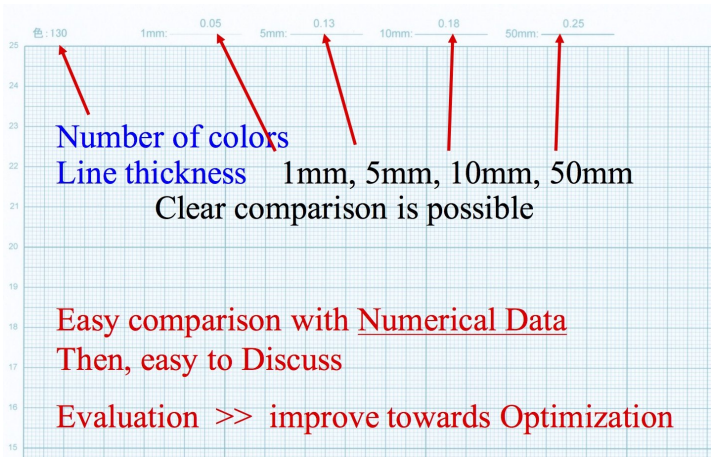


Figure 3: Creation of section paper

available. We believe that the students can achieve optimization only through working together with other group members. In addition, it makes it possible to evaluate all students in the class and consider and discuss section papers created by individual groups while specifically referring to numerical data (Figure 3).

4.2. Manufacturing by CAD of paper plane and paper car

The subject tasks are *"Production of Paper Planes and Joining the Flight Contest"* in the first year, and *"Production of Paper Car (Paper-made Car) and Competing in the Time Race"* in the second year. In each of these, students produce paper planes and paper cars with the use of CAD in accordance with different manufacturing conditions. In each subject, the level of completion of the product is measured with the record of flying distances and running times. Therefore the students make an effort to repeat their improvements to raise the level of completion. The competition is measured fairly by comparison and evaluation of each participant's performance.

Figure 4: Paper plane competition. Toward the 7 m destination of the pass line, check for flight distances of own paper airplane

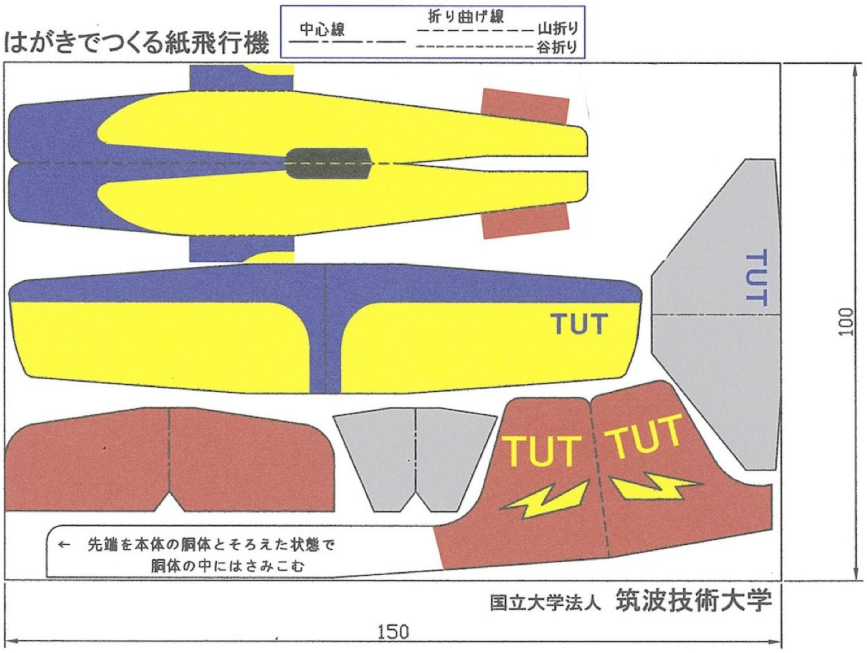


Figure 5: Making Paper Planes from Postcards Sized Paper – all parts must be drawn within a size of a postcard

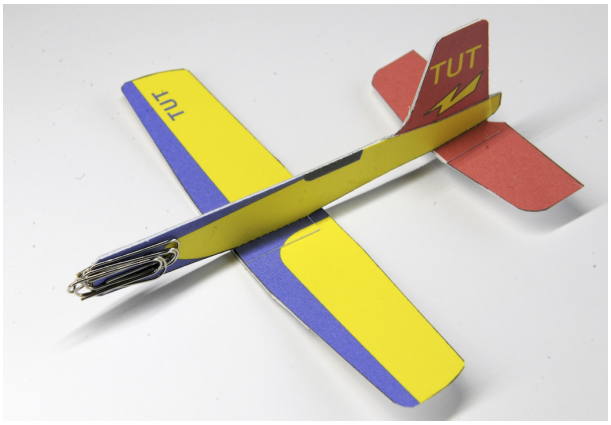


Figure 6: Paper Plane. Using paper clips to the paper airplane as weight for balancing

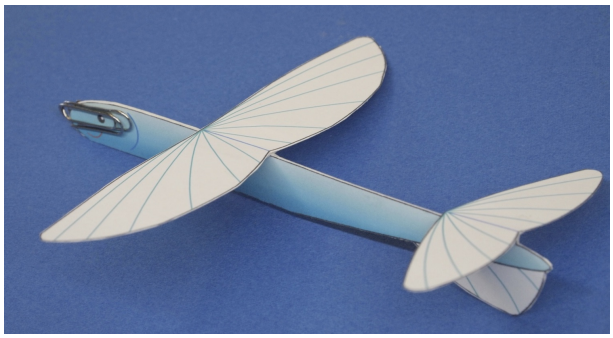


Figure 7: Flying fish Paper Plane

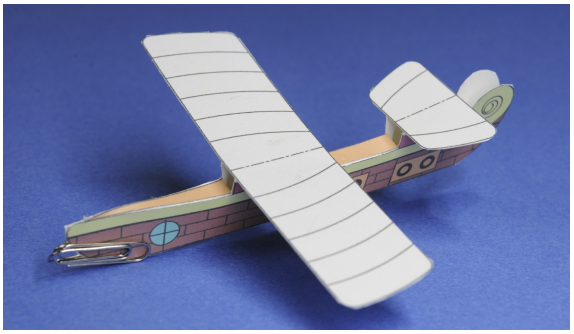


Figure 8: Sailboat Paper Plane

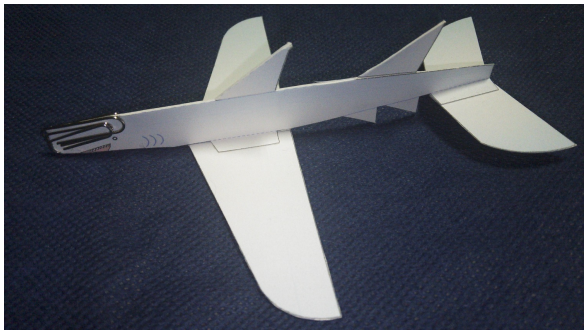


Figure 9: Shark Paper Plane

The manufacturing of a paper plane consists of the following steps: drawing all the parts within a frame of postcard size, printing out the drawing on Kent paper, cutting the parts, assembling the plane with a bonding agent and maintaining the balance of the plane with clips as weight. In the contest, they compete on how far the plane flies after they are thrown by hand. Up to the contest, they continuously make improvements to the plane so that it exceeds the examination criteria of 7 m. Each of the students throws the plane 3 times and the longest distance is adopted as the record for the competition (Figures 4–9).

The production of a paper car consists of the following steps: design, preparing the drawing, printing out the drawing on Kent paper, cutting the parts, and assembling the car with a bonding agent. The size of product has limitations, a maximum length of 200 mm and a maximum width of 200 mm. The material used in the construction of the body, including the tires and the driving wheel pulley, is Kent paper except for the wheel shaft which is made of a wooden round bar with a diameter of 5 mm. A Mabuchi FA130 motor is used for the models with a plastic pulley, wired with a 2 AA battery holder, which is mounted onto the body. The paper car runs by power transmission with a rubber band. In the race, the students compete on how fast their cars run on a straight course of 15 m. The NTUT students start the preparation by meeting the schedule for the car race, a race between the NTUT and the Tsukuba Gakuin University (TGU) in Tsukuba City is then held first. The race is a traditional event which has been held between the NTUT and the TGU since 1993.

Apart from this, the NTUT has held a car race with a sister school in China every year since 2002, in which the race scenes are relayed via videophone. This is an enjoyable event in which the students introduce themselves and show their cars mutually via videophone during the intervals of the races, and then finally select the best car from each country to receive a Good Design Award. The race is held as part of Collaborative Education among classmates, as well as students in other universities and students with hearing impairments from overseas universities. It has an immeasurable significance to the students as they make their best efforts in sharing a goal through collaborative study, and results in the learning of fellowship and culture as they broaden their horizons (Figures 10–15).

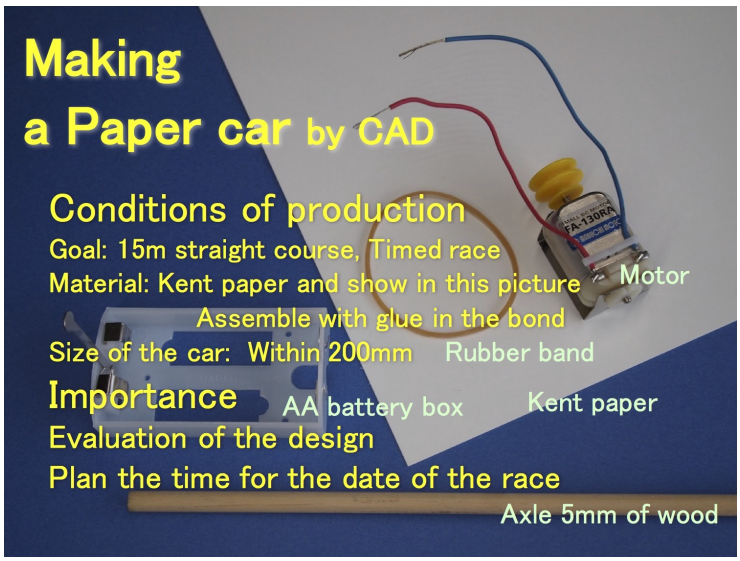


Figure 10: Conditions of production for making a Paper Car – using the same parts

Figure 11: Paper car race at the Japanese side, Tsukuba Gakuin University versus NTUT. Chinese students are looking at through live monitor at Changchun University, China

Figure 12: A Japanese student is showing his own car to the Chinese students from Tsukuba/Japan through video conferencing system

4.3. Participation in paper plane workshop (social contribution)

In Tsukuba City in spring, universities, laboratories and schools open hands-on events for local children, sponsored by the tourism division in spring and by the board of education in autumn. The NTUT dispatches its students as instructors to this *"Workshop in making and flying paper planes"*. Students interact with the local residents and present their own drawings of paper planes and give directions to children on how to make and fly a plane. Students participate in the workshop as a first step in Collaborative Education and also as part of their social contribution. Students participate in this traditional event, which has seen satisfactory results in the past, as a first step in their inclusion into adult society and in which

Figure 13: A Chinese student is showing her own car to the Japanese students from China, evaluating the work by each other

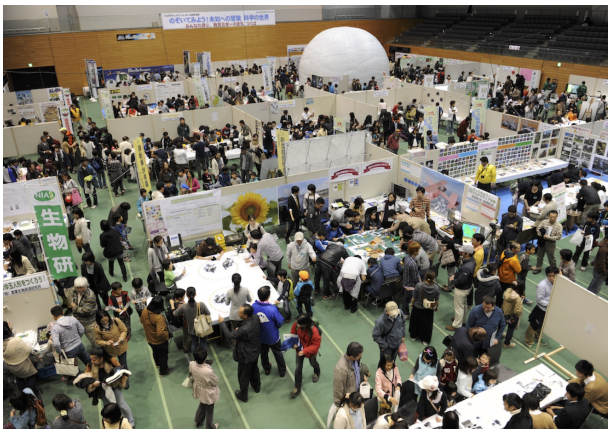
Figure 14: Group photo with students of the Chinese side on the monitor

they exercise mechanical designs and drawings as done in the class. This program is intended to involve the students in the local community, as they can be too nervous while trying to communicate with the general public. During the workshop, both children who have a strong desire to make a plane, and their parents, who become completely absorbed in the work, listen carefully to the explanations made by the students.

Children will select their own favorite planes, and students will teach them how to make and fly the ones selected. Taking into consideration the results of spring event, including whether the student's own plane designs were selected by the children or not, the students will try to increase the value of their product by improving its color and shape so that their planes

Figure 15: Changchun University, China. Stimulated exchange

will be selected, to be made, by the children in the autumn event. If the planes designed by the students are selected by the children, and if the planes achieve their intended performance, a public evaluation will be made by the general public. This is a supportive effort in education involving society as a whole as well as a good event in which we are grateful for taking part in, as it provides a good opportunity to facilitate the growth of the students (Figure 16).



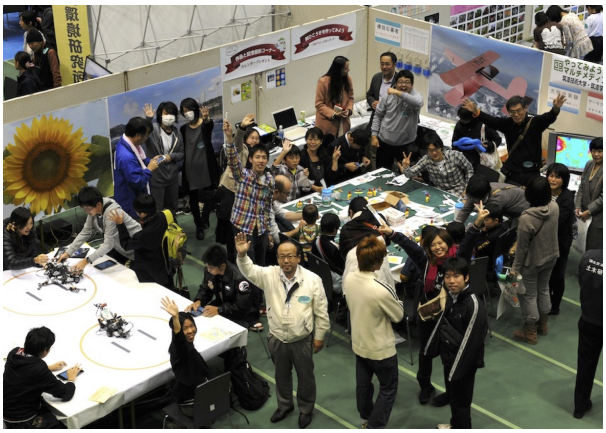


Figure 16: Workshop at Tsukuba Science Festival, *"Build and Fly! Paper Plane"*

4.4. Development with CAD to collaborative education

In the second year, students manufacture a display stand for the paper planes which were made in the design and drawing exercises in the first year. An acrylic board with a thickness of 3 mm is used as a material in construction. The work is done by a team consisting of a designer and produced as follows: the designer prepares a handwritten drawing, based on which the manufacturer prepares CAD data, and a product is shaped by a laser beam machine according to the CAD data. Students will recognize that the accuracy of the handwritten drawing is

essential, because the drawing has a role in transferring information. It takes time for students who are familiar with sample drawings in the textbook to work with handwritten drawings. They need to accumulate experience. The skill of the producer during the processing does not matter, as long as the handwritten drawing prepared by designer is accurate, the CAD drawing developed from the handwritten design should also be accurate, so that the laser beam machine produces the display stand exactly as shown on the CAD drawing (Figure 17).

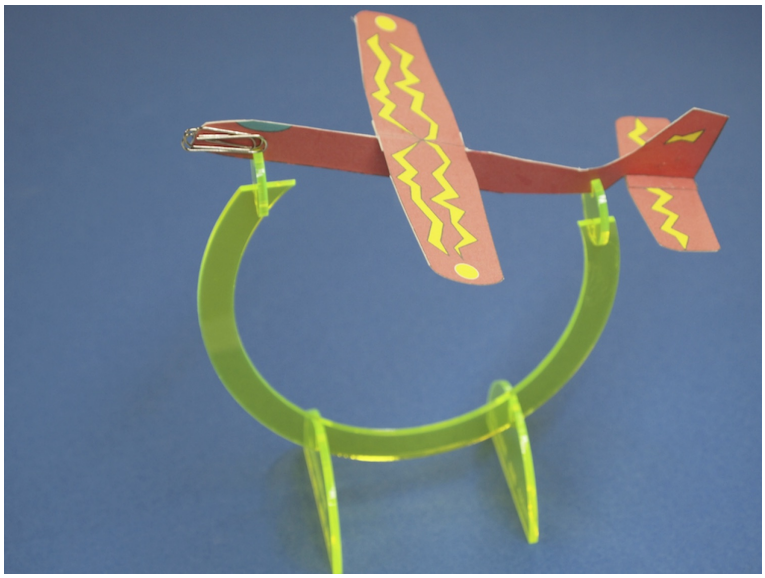


Figure 17: Display stand for own paper plane

Collaborative work becomes easy after the start of class for 3D drawing. Students draw a hand-winding winch CAD/CAM exercise in the latter half of the first term in the third year. Students are divided into groups of 4 or 5 and a leader (in charge of assembly) is selected. The winch is assembled from parts which the individual group members design, draw and manufacture. When the plastic parts produced from 3D CAD drawing are assembled into a product, it will be confirmed as to whether those parts can be really assembled or not. Therefore it is essential to consider any dimensional deviations and other conditions regarding design. The clearance in the assembly of the plastic parts is different from those in metal, but students can still learn through the assembly of the plastic parts as a model reveals that it is important to consider machining accuracy among other things in design drawing (Figure 18).

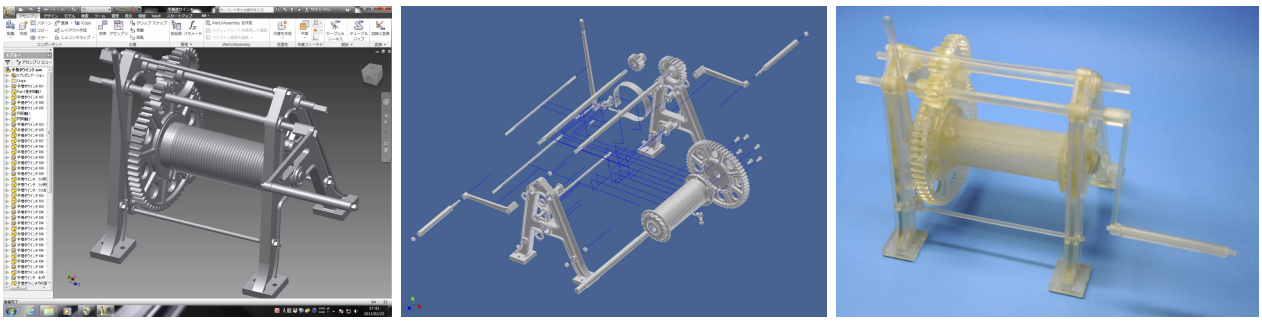


Figure 18: Hand-winding winch as a collaborative work. The winch is assembled from parts which the individual group members design, draw and manufacture by 3D RP modeling machine

4.5. Development with CAD from Collaborative Education

Handwritten drawings are displayed so that students can mutually evaluate and discuss which ones are good while citing the reasons. In the case of the handwritten drawings, everybody can see the progress they have made starting from the drawings on drawing board, while in case of CAD drawing, the progress of drawing cannot be instantly judged except by its drawer, as the image is formed on a monitor.

Therefore, individual drawings being made by students are displayed in turn on a monitor on the lecturer's desk as well as on a large monitor common to the classroom so that students can share the progress of all the drawings. However, the student's individual questions or lack of understanding cannot be highlighted until the drawing is completed.

To improve on such a situation, the name of students who have completed drawings achieving the essential features of the work are written down on a whiteboard, so that students who have already understood can teach those who have not yet understood, so enhancing the level of the class as a whole. In the 3D CAD drawing class, students produce 3D models based on the CAD data they have provided. The models are displayed in the class so that the students can examine the models to be made aware of their mistakes, even the small ones, all by themselves. 3D drawings accompanied with drawing numbers and the names of the students are publicly displayed to all the students in the class, as well as to visitors, as an achievement of their studies.

In addition, the NTUT dispatches students from the CAD/CAM room to an event of research presentations and lectures for students at the Bauman Moscow State Technical University (BMSTU) in Russia called *"Step into the future"* (Figure 19).

At this event, research presentations regarding CAD are held through video conferencing with the NTUT as part of an international collaboration. The research presentations made here encourage students who participate in it to gain confidence, and give an opportunity to play an active role in the world. Students are given an opportunity to participate in international collaboration, in which they make a good use to study for the preparation, to summarize their performance and then present their research results. Students can enjoy such a kind of experience thanks to the NTUT's universities overseas. It is important to know mutually that students are making their best efforts in the research presentations regardless of the countries they belong to, as these will offer a lot of encouragement to and help them to become highly independent in society.

5. Summary

Student participation in traditional events using CAD and 3D modeling as part of their study has evolved into Collaborative Education, which involves cooperation and passionate efforts in Mechanical Design and Drawing/CAD education. Accurate communication has been made possible, as it is easy to transfer the information of images through models. We further expect the educational effect to induce the student's awareness by way of models produced from 3D modeling, and we also believe that the effective use of the above mentioned practices contribute to the future development of design and drawing education as well as provide support for the students' high degree of independence in our society.

Figure 19: Poster from BMSTU for students' science competition *"Step into the future"*. The poster shows participating students from NTUT through video conferencing system

References

[1] T. Araki: *The Study on the Development Teaching Materials in the Mechanical Design and Drafting Contains a CAD in a College Education for the Hearing Impaired.* Proceedings of the Japan-China Joint International Conference on Graphics Education, Wuxi/China 1993, pp. 197–202.

[2] T. Araki: *Basic Education of CAD/CAM through Multimedia and Modeling.* Proceedings of the 2nd Japan-China Joint Conference on Graphics Education, Chengdu/China 1995.

[3] T. Araki, S. Hirano: *Learning about Mechanical Design and Drawing through the Experience of 3D modeling.* Proceedings of the 15th ICGG, Montreal/Canada 2012, pp. 28–35.

[4] T. Araki, S. Hirano, S. Kise, S. Sekiguchi, K. Okusaka, R. Wada: *Learning Through the Use of CAD and 3D-RP Modeling (From Experience by Collaboration and Communication).* Proceedings of the 3rd International Conference on Design Engineering and Science — ICDES, Pilsen/Czech Republic 2014.

[5] T. Araki, S. Hirano: *Development of cooperative education and basic engineering education: aided by 3D CAD and 3D RP modelling.* Int. J. Comput. Appl. in Technology **51**/1, 80–85 (2015).

[6] T. Araki, N. Nakamura and I. Honma: *Educational Assistance Through Modeling in Tsukuba University of Technology of Professional Education for the Hearing or Visually Impaired.* Comput. Aided Drafting, Design and Manufacturing (CADDM) **25**/4, 58–65 (2015).

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