

# Educating Students in Universal Design using a Digital Mannequin

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## Abstract

This paper discusses the educational program of universal design (UD) using a digital mannequin at Kinki University. A digital mannequin is a virtual human model that can evaluate the usability of a product in a 3D-CAD system during the design process. During the course, after training in 3D-CAD product modeling and 2D-CAD mechanical drawing, students commence exercises on the design of UD products using a digital mannequin. This paper discusses the course in detail.

**Keywords:** universal design, digital mannequin, CAD, education, usability

## 1 Introduction

The population of elderly people in Japan annually increases. The percentage of the population over 65 years of age exceeded 24 percent in 2012 [1]. Ageing has become one of biggest issues in Japan.

As age increases, his or her degree of physical performance decreases. Elderly people sometimes experience difficulties using products because some of the products require a high degree of physical performance. Some disabled people, pregnant females, and children are especially vulnerable because their physical performance tends to be lower than those of a typical adult male. In addition, people sometimes experience difficulties when their physical performance decreases; for example, they cannot open a door while carrying heavy baggage. Such difficulties are eventually faced by everyone.

Universal design (UD) [2], [3], [4] strives to design products for all people considering all situations. To design a highly efficient UD product, engineers need to obtain UD skills. The students in our department study both the concept and techniques of UD. During the course, the students learn the techniques to analyze the usability of products modeled with 3D-CAD using a digital mannequin and improve their usability. In Japan, a number of universities have commenced 3D-CAD education programs [5], [6]. However, they do not teach UD techniques using a digital mannequin. This is the first trial of teaching computer-aided UD to as many as 80 students in one room.

This paper discusses the courses of computer-aided UD at Kinki University. Section 2 mentions the education of computer-aided UD, Sec. 3 and 4 describe the overview and the course program, and elaborates some examples submitted by the students, respectively. Section 5 presents a summary of the manuscript.

## 2 Education of computer-aided UD

### 2.1 Universal design

UD is a design concept that is implemented in such a way that the usability of products is guaranteed to all users in any situation. Ronald Mace et al. proposed “The Principles of Universal Design” [7] and many UD products are based on these principles. For example, principle six which concerns “Low Physical Effort” is implemented using examples including a low-floor bus that enables elderly people or children to board the bus without much effort.

### 2.2 Computer-aided UD

#### 2.2.1 Computer-aided design

The usability of a product is usually determined by a person in the latter stage of its design process. If the usability of the product is deemed to be insufficient, the designers should ideally revert to the upstream stage of the design process, which increases the lead time of the design process and its cost. To improve the usability of a product and realize its UD capability in a shorter period of time, the usability should be determined in the early stages of the design process.

Using a digital mannequin with a 3D-CAD product model, it is possible to determine product usability by computational analysis. For example, principles six and seven, which concern “Low Physical Effort” and “Size and Space for Approach and Use” [7], respectively, can be analyzed physically and geometrically using computer software.

#### 2.2.2 Digital mannequin

A digital mannequin is a virtual human model that can be applied to evaluate the usability of a product made using 3D-CAD and can be used to investigate both the ergonomic design and UD of a product as shown in Figs. 1–6 and 8.

A UD product can be designed on the basis of analyses of its usability evaluated with various users’ body types. Since a digital mannequin is a virtual human model, various types of users can be easily evaluated and its use maintains a low evaluation cost.

### 2.3 Education of computer-aided UD

To efficiently design UD products and improve their usability using a digital mannequin, it is important for product designers to learn the correct procedure for designing UD products.

Today, many designers obtain such knowledge and skills by trial and error based on the job training. If they are systematically trained, they can efficiently obtain the required skills and knowledge.

### 3 UD and CAD exercises

#### 3.1 Overview of the department's curriculum

The Department of Biomechanical and Human Factors Engineering at Kinki University was established in 2010. Its aim is to train students who can design products based on the concept and methods of UD.

The students in our department learn about human beings and product design methods in depth by studying subjects including mathematics, physics, human science, mechanical engineering, medical and welfare engineering, and environmental science, etc. In addition, they can obtain the skills for designing products with a high usability by integrating their knowledge through product design exercises.

#### 3.2 Overview of UD and CAD I and II exercises

The students obtain the skills for designing UD products using CAD and a digital mannequin in UD and CAD I and II. The courses are available in the third and fourth semesters, respectively, and are compulsory.

The two courses have 30 classes in total within the two semesters. The courses consist of three main topics:

- (1) 3D-CAD modeling: The students do the exercises for 3D-CAD modeling because they must create a 3D-model of a product to analyze its usability and develop its design.
- (2) 2D-CAD drawing: The students do the exercises for 2D-CAD drawing because engineers should be able to understand and draw 2D-drawings of products.
- (3) Ergonomic design and UD using a digital mannequin: (3A) The students first learn the basic operations of a digital mannequin such as posture changing, interference analysis, balance analysis, static load analysis, and view analysis. (3B) They then work on the ergonomic design and UD of daily use products. Finally, they complete the UD project.

Topics (1)–(3A) are practiced in UD and CAD I and (3B) is practiced in UD and CAD II.

#### 3.3 Computer resources

The courses are conducted in the department's computer room. There are 110 PCs in the room and all of the students take the courses together.

The specification of the PC is described below (the PCs are replaced with higher performance ones in March, 2014):

- Product: Dell Optiplex 755
- Specification: Intel Core 2 Duo 2.33GHz CPU, 2GB Memory, HDD, 17" LCD monitor
- OS: Windows XP SP3
- Software: AutoCAD 2009, Body Shape Designer (BSD) developed by Ergovision Ltd., ANSYS ED, Microsoft Office 2007

A digital mannequin software BSD is a plug-in software of 3D-CAD software AutoCAD. It can be used to analyze the usability of a product model in AutoCAD such as a posture during product use, an inference between a mannequin and a product or another mannequin, view of a product, and static loads (force and torque) assigned to each body part based on the posture of the mannequin, etc. BSD analyzes them

based on the posture and the external force etc. which are assigned by the user and the user can dedicate themselves to developing the design of a product. The mannequins in BSD are created based on the database of a typical Japanese body type following research by the Institute of Human Engineering for Quality Life (HQL).

The computer room is also used for other courses in our department such as finite element method (FEM) analysis, computer programming, exercises for freshmen, data analysis and writing reports on experiments, etc. The students can use the room in their free time for private study if the room is vacant.

### 4 Details of UD and CAD subjects

#### 4.1 3D-CAD modeling

The students create 3D-models of products from the first to the third week of UD and CAD I.

After they learn the basic operations of 3D-CAD software, they make a T-shaped stick model and a bench model that are used to analyze product usability using a digital mannequin as shown in **Figs. 1** and **4**.

#### 4.2 2D-CAD drawings

The students use CAD software to complete mechanical drawings of products from the fourth to seventh week of UD and CAD I.

First, they learn the basic operations of 2D-CAD software. They then produce drawings of a T-shaped stick and a bench which they made in the 3D-CAD modeling section.

#### 4.3 Ergonomic design and UD using a digital mannequin

The students design UD products by analyzing the usability of the products using a digital mannequin in 3D-CAD. First, they learn the basic methods of analyzing the usability of products using a digital mannequin for eight weeks until the end of UD and CAD I. In UD and CAD II, they learn the ergonomic design and UD of daily use products using a digital mannequin for 15 weeks.

Before commencing with a digital mannequin in the eighth week of UD and CAD I, Mr. Shozo Hirose, an engineer who developed BSD, the digital mannequin software used in the courses, lectures the students about the latest trends in digital mannequins in Japan and also worldwide. It is a great help for the students to know the role of a digital mannequin in product design.

##### 4.3.1 Basic operations

###### (1) Posture changing (eighth and ninth week)

Changing the posture of a digital mannequin is the most basic skill for usability analysis. The students learn the skill in the eighth and ninth weeks of UD and CAD I. They make the postures used in radio gymnastics in Japan as an example.

###### (2) Interference analysis (tenth week)

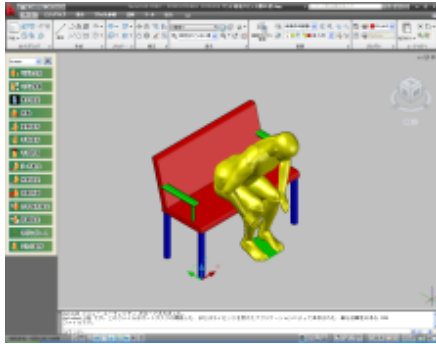
Interference between plural objects does not occur when a user uses a product. The students learn how to detect interference between objects in the tenth week of UD and CAD I.

They make a mannequin sit on a bench and analyze the interference of the mannequin with the

bench and the ground.

(3) Balance analysis (eleventh week)

The mannequin should be balanced while it uses a product. The students learn balance analysis in the eleventh week of UD and CAD I. **Figure 1** shows the balance analysis at the moment when a mannequin stands up from a bench.

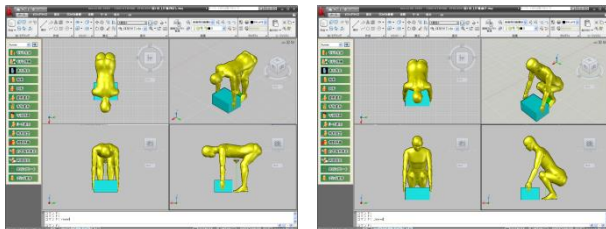


**Fig. 1 Balance analysis in standing up from a bench**

(4) Load analysis (twelfth and thirteenth week)

The load applied to a user is one of the most important factors for product usability. The students learn how to estimate static loads when a mannequin uses a product in the twelfth and thirteenth week of UD and CAD I. **Figure 2** shows examples of the assigned postures. They analyze the moment at every joint and compare the moments in the postures.

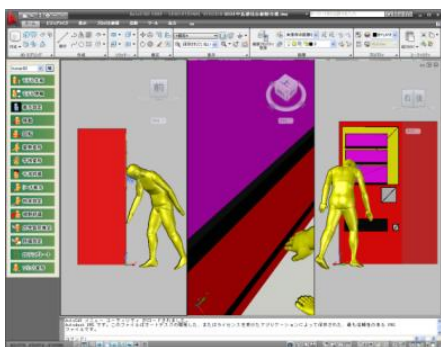
During the course, the students evaluate force and moment at all joints of a mannequin during product use in various postures.



(a) Holding a box with knees stretched

(b) Holding a box with knees bent

**Fig. 2 Static load analysis**



**Fig. 3 View analysis in taking a can from a slot**

(5) View analysis (fourteenth and fifteenth week)

The view in using a product is also an important factor. The students learn how to analyze views in the fourteenth and fifteenth week of UD and CAD I. The middle section of **Fig. 3** represents view analysis when a person takes a can from a vending machine slot.

In the fifteenth week, the students also take an examination on evaluating the usability of a product using a digital mannequin. It helps the students develop the skills for evaluating product usability.

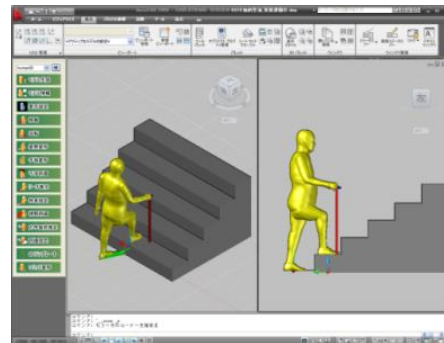
4.3.2 Ergonomic design and UD of daily use products

In UD and CAD II, the students examine the ergonomic design and UD of daily use products by considering their usability. During the course, each student analyzes and designs products for an assigned mannequin of a particular body type based on a combination of characteristics such as age (young/elderly), sex (male/female), height (tall/medium/short), and waistline (big/medium/slim).

The authors also strongly recommend the use of actual products to feel their usability.

(1) T-shaped stick (first and second week)

In the first week of UD and CAD II, the students adjust the shaft length for the assigned mannequin under a guideline [8]. The optimal shaft lengths are gathered from the students to investigate the relationships between human height and shaft length. In the second week of UD and CAD II, they analyze the loads in walking on a flat floor and climbing up and down a flight of stairs with the stick. **Figure 4** shows the posture in climbing up a set of stairs with a stick.



**Fig. 4 Climbing up a set of stairs with a stick**

(2) Bicycle (third and fourth week)

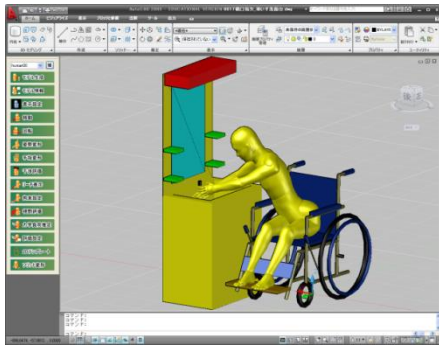
In the third week of UD and CAD II, the students create a 3D-model of a bicycle. Before they create it, they observe an actual bicycle and draw a sketch by themselves based on an example to ascertain the structure of the bicycle. In the fourth week of UD and CAD II, they analyze the posture and loads during riding and modify the design to make it easier to ride.

(3) Wheel chair (fifth and sixth week)

In the fifth week of UD and CAD II, the students make a 3D-model of a wheel chair based on a 2D-drawing of the wheel chair, which helps them to create a 3D-model based on a complicated 2D-drawing. In the sixth week of UD and CAD II, they analyze the posture and loads during use. The wheel chair is used in subsequent assignments as shown in **Figs. 5** and **6**.

(4) Lavatory (seventh and eighth week)

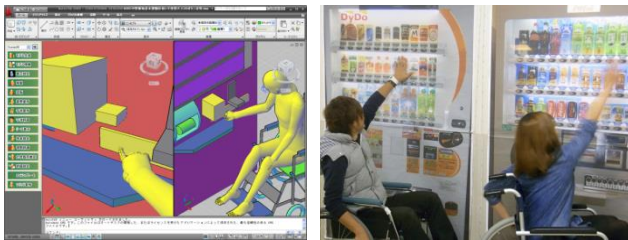
In the seventh week of UD and CAD II, the students write reports on a lavatory and the factors that make it harder-to-use. They then make a 3D-model of a lavatory and analyze the various postures such as washing hands, washing hair, shaving, etc. In the eighth week of UD and CAD II, they modify the lavatory and analyze its usability. For example, **Fig. 5** shows the posture of a female on a wheel chair washing her hands with a lavatory.



**Fig. 5 Posture of a wheel chair user washing hands**

(5) Vending machine (ninth and tenth week)

In the ninth and tenth weeks of UD and CAD II, the students create a 3D-model of a vending machine based on UD and compare its usability with that of a traditional vending machine taking into account factors including posture, view, load in pushing a button, and taking a can, etc. as shown in **Fig. 6(a)**. At least three body types (e.g., adult, child, adult on a wheel chair) are used to evaluate the usability. To experience the usability for a wheel chair person and a child in purchasing a can from the two types of vending machines, they sit on a wheel chair and enact the purchase process in front of their real scale panels as shown in **Fig. 6(b)**. They then propose more usable vending machines based on the evaluation.



(a) Pushing a button of a UD vending machine (b) Experience of the two types of vending machines

**Fig. 6 Usability analyses in using vending machines**

(6) Design project (from eleventh to fifteenth week)

The students discuss the usability of products with their project members and propose UD products from the eleventh to fifteenth weeks of UD and CAD II.

In the eleventh week, after all students are divided into three member groups, they discuss the problems of

various products within each group and decide which product they will redesign. In the twelfth week, they make a 3D-model of that product and analyze its usability using a digital mannequin. In the thirteenth and fourteenth week, they develop the design based on an evaluation of the usability for several body types (e.g., a young tall male, an elderly short female on a wheel chair, etc.). In the fifteenth week, they give an oral presentation on an existing product and a proposed design with their usability analyses.

Some of the selected products were a closet, a refrigerator, a washing machine, a vacuum, a suit case, an automatic toll gate in a railway station, a bathroom, etc. **Figure 7** shows some scenes in a design project. **Figure 8** shows examples of proposed designs. **Figure 8(a)** shows a proposed closet design: it is easy for a wheel chair person to take a cloth by pulling down the hanging bar. **Figure 8(b)** shows a proposed refrigerator design: a child can easily take a can by pulling down the bottle pocket.

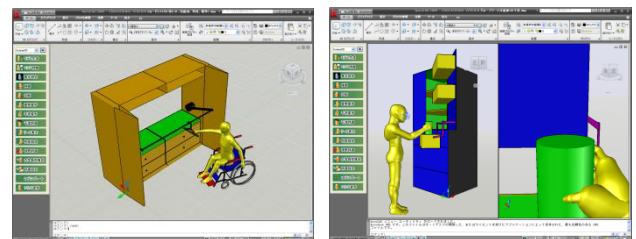


(a) Experiment of the load in climbing up stairs (b) Posture in riding a wheel chair



(c) Discussion with project team members (d) Presentation on a proposed design

**Fig. 7 Scenes in design project**



(a) Proposed closet (b) Proposed refrigerator

**Fig. 8 Examples of design project**

**4.4 Assignments**

Since the students have various learning levels in using a digital mannequin, it is difficult for all students to solve all of the assignments. Therefore, three types of assignments are given to the students. They are (a) required assignments, (b) additional assignments, and

(c) free assignments. The students must hand in all required assignments. Those who have handed in the required assignments can tackle additional ones. Those who have finished additional assignments can tackle free assignments, in which they propose a situation to be solved and provide the solution. The scores of additional and free assignments are added to their grade. Some of them are given as homework so that the students tackle them to improve their skills.

#### 4.5 Effects of the exercises

The effects of the exercises can be evaluated by the students' skill on the analysis and development of a product usability using a digital mannequin. The former can be evaluated by the examination in the fifteenth week of UD and CAD I. In 2012, they evaluated the usability of a desk. They analyzed the load and the view of a mannequin sitting on a chair while it is looking into the bottom drawer of the desk to take an object. All of them could evaluate it adequately. And the latter can be finally evaluated by the design project in the UD and CAD II. They discussed the usability of a product, made its 3D-model, evaluated its usability and redesign it to develop its usability using digital mannequin.

Some comments which the students gave after UD and CAD I and II finished are as follows:

- [Good point] I could obtain the skills on CAD and a digital mannequin step by step.
- [Good point] I could feel the usability using actual products. It helped me to think of their usability analysis using a digital mannequin deeply.
- [Good point] The enough time for exercises was secured and I could tackle the exercises satisfactorily.
- [Bad point] It is necessary to give adequate explanations on the operation of software and exercises.

### 5 Conclusions

This paper discusses the study of UD and CAD at Kinki University. During the course, the students learn the necessary skills to develop a UD product using a 3D product model and a digital mannequin.

The authors are planning to improve a number of

aspects of the course including the design method of products based on their usability analysis, and procedures involved in the design project, etc.

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