# Estimation model of training support system for Finite Element Analysis and implementation of training scenario as knowledge patterns

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## ABSTRACT

This paper presents an arrangement method of FEA modeling knowledge by using a design pattern methodology, and deals with an estimation method of FEA training scenario. The prototype support system and its training knowledge can be arranged and classified in several patterns, while the mechanics of a beam structure has been picked up as an example of training subject. Essential evaluation problems were prepared for checking the synthetic achievement and the effectivity of training support system onto any beginners of the code called MARC/MENTAT has been investigated. Through the simulation with the prototype training support system, an evaluation model as the synthetic achievement test for any training scenario was shown with the degree vector. Observing the reusability of training programs, the compression rate of iterated common operations was estimated for the prototype training support system.

**Keywords**: achievement of learning, knowledge pattern, finite element analysis, case reasoning, analogy

## 1. INTRODUCTION

There are well-known many general-purpose FEA(finite element analysis) code[1][2] such as MARC, ABAQUS, NASTRAN, ANSYS and COSMOS, in order to analyze successfully the strength of structural material or the behavior of non-structural thermofluid dynamics without development of huge complex source codes. They can be applicable to any engineering problems as intelligent black boxes. However, it is not easy to design the input data for such the codes(FEA processors), because there are many peculiar grammars, preconditions, or restrictions which cover changes in boundary conditions, variability of material properties and coupled problems. In order to design physically based semantic attributes by the use of the code grammar, empirical but logical knowledge is fundamental to idiomatic composition of sentences and restriction in composition, and is required for simplifying various conditions or evaluating the accuracy in calculation. Theoretical knowledge of the fundamental mechanics and empirical operating knowledge of the codes are needed to users of the codes, in order to decide reasonably the model parameters and to grasp the various multifunction of the code. The users do not sometimes understand the public restriction of the grammar and physical characteristics correctly.

The authors have been studied the methodology of FEA support system development for such needs[3][4]. Development of the smart retrieving engine for any related FEA examples was also investigated[5]. However, the trial-and-error correction of input data is usually repeated in the reference to the error results from the code or from the operating system. It is not easy and competent for beginners to read sequentially the user's manuals, while an excellent specialist can classify various error results, can search the location of error, and can take quickly the measures to the situations. Hence, any instruction method for handling imperfect input data should be formulated, and any estimation method of scenario performance should be shown for learning how to design the FEA model.

In this paper, the authors propose firstly a constructing method of FEA modeling knowledge, conceptual classes, based on a design pattern style[6], for applying the knowledge classes to a training support system. By using the design pattern technology, the prototype support system and its training knowledge can be arranged and classified in several patterns as a framework for the training support system. The prototype system has been developed with WEB database. Besides, several but essential evaluation problems were prepared for checking the synthetic achievement, and the effectivity of training support system onto any novices of the code, called MARC/MENTAT[7][8], has been investigated.

## 2. DESIGN PATTERN OF FEA MODELING

### 2.1 Knowledge of applied mechanics for FEA

Let us pick up a beam mechanics as an FEA problem to be solved. For solving this problem, there are three stages in general. The first one is declaration of mechanical conditions or assertion of specification with a physically simplified model. The next one is approximation from the physical model to a mathematically discrete model. The third one is how to handle any FEA processor, namely, to show any grammatical knowledge based on many restricted functions or assumptions. Observing these stages as modeling knowledge, we can know that all of them are composed of many attributes for describing details of the problem to be solved. The physical knowledge, the mechanical conditions such as laminated, notched, supported in one side, deformed under a point load, and composed with several metals, can be seen as a hierarchically related knowledge. **Fig.1** shows a class pattern for cantilever mechanics. They are related to the first stage mentioned above. The second stage is a translation, replacement from any physically ideal models to other concrete data format or appropriate processing algorithms. They are certain kinds of action(conduct) patterns[9], that are used for creating any extended target. The third stage is also other action(conduct) patterns based on the processor functions. They can be understood as the private methods or certain kinds of macro-commands for interaction and solving the specified problem. **Fig.2** shows the flowchart of training support for FEA modeling. In the following work, some problems of the beam mechanics to be solved with any FEA tool were arranged semantically as Class objects.

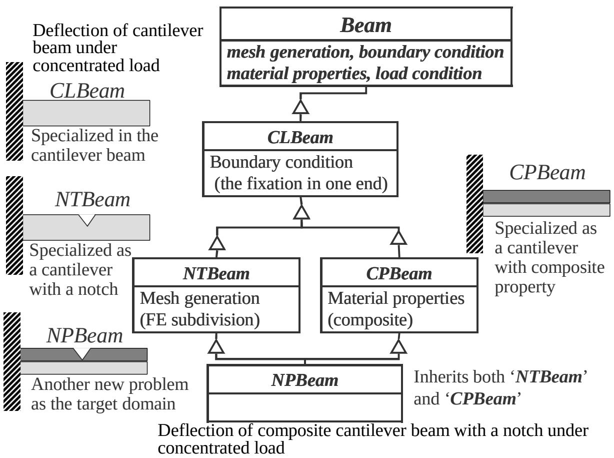


**Fig. 1 Design pattern for cantilever mechanics**

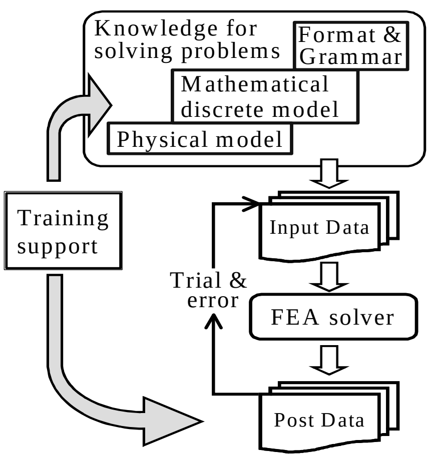


**Fig. 2 Process flow of training support for FEA modeling**

**2.2 Modification analogy from base domain to target domain**

In the process of designing FEA input model, novices can learn the next two procedures and can follow these cases.

a) A procedure such that the design parameters are specialized by adding each condition gradually, being started from an example of general-purpose modeling.
b) A procedure such that the design parameters are specialized by combining several examples of general-purpose modeling.

In such the process of modeling, the user's knowledge required for modeling will change to a specialized knowledge in the target domain from a general-purpose knowledge in the base domain. It is supposed that the most of concrete target domains can be generated by modifying or replacing partially the base domain knowledge. For an example, a beam problem is considered here. **Fig.3** shows a flow of deployment from an analysis problem as the base domain to new analysis problems in two target domains.

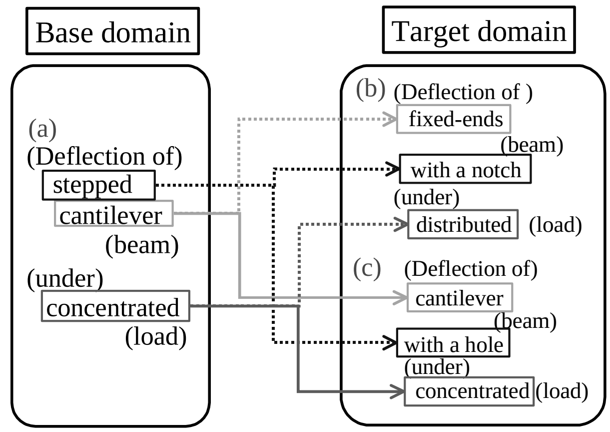


**Fig. 3 Deformation from base domain to target domain (Carrying over similarity with attributes of the beam)**

Here, the base domain problem is the analysis(a) of deflection of a stepped beam which is fixed in one end and subjected to a concentrated load, while the target domain problems are firstly the analysis(b) of deflection of a notched beam which is simply supported in both sides and subjected to distributed loads, and secondly the analysis(c) of deflection of a cantilever beam which has a hole in the middle and is subjected to a concentrated load. For deriving the conception of "*distributed loads*" on the discretization modeling from "*a concentrated load*", a modification analogy, such that any distributed loads must be composed of any concentrated loads adjoined with each other, can be imagined for the load condition. For deriving "*the notch on a structure*" and "*a hole in the middle position of a structure*" from "*a stepped shape of a structure*", an analogy on any mechanical elements is carried over the discretization as subdivision of Finite Elements. Namely, an FE subdivision of a stepped shape must be applicable to other FE subdivision problems such as a notched shape or a beam with a hole, because of its geometrical similarity. Moreover, an analogy on any constrained conditions of displacement is carried over the discretization as FE subdivision: the fixation on both ends of a beam is derived from the fixation on one end of a beam.

**2.3 Application of design pattern to a beam mechanics problem**

The modification analogy from base domain to target domain is recognized that some attributes of the base domain problem are abstracted and extended to the semantically similar attributes of the target domain problem. It is recognized that the analysis case(b) inherits the analysis case(a) and also the analysis case(c) inherits the analysis case(a). By observing "*the support of FEA modeling*" as a framework of any object patterns, extraction and identification of new attributes from the base domain to the target domain are attained. Forming a kind of knowledge pattern(architecture of training scenario), which depends on the attributes of the domain, is desired for leading any user to the target domain problem. Forming such the knowledge pattern is equivalent to support friendly the users by optimizing or customizing the training scenario of FEA modeling. When a training analysis of a beam mechanics is considered, a design pattern shown in Fig.1 can be picked up as the hierarchical (inherited) subclasses of applied problems. "*Beam*" superclass which is abstracted from the base domain, the analysis case(a), has some attributes such as "*boundary condition*", "*mesh generation*", "*material properties*" and "*load condition*". "*CLBeam*" class which is specialized in the cantilever problem, the base domain, has another boundary condition replaced by the fixation on one end. "*NTBeam*" and "*CPBeam*" classes are defined as two subclasses of this class. "*NTBeam*" is specialized as a cantilever with a notch, while "*CPBeam*" is specialized as a cantilever with composite property. Similarly, "*NPBeam*" with both the notch and the composite property, that inherits both "*NTBeam*" class and "*CPBeam*" class, is available as another problem of target domain. For the modification analogy of geometrical shape, the distribution pattern of the strain and the distribution pattern of the stress of a beam structure should be considered. If the stress distribution of one structure is similar to the stress distribution of another structure, they may have almost the same pattern of FE subdivision. The distribution pattern of stress concentration in a notched element depends on a couple of geometrical parameters, such as the root radius, the bevel angle and the groove depth. Therefore, in order to consider the stress concentration in the circumference of a notch, the mesh pattern of "*NTBeam*" should be customized(specialized). Namely, the procedure attribute "*mesh generation*", which was defined in the superclass, should be replaced by another rule of subdivision. Similarly, as the combination pattern of laminate controls the deflection or the stress distribution, the attribute "*material properties*" should be noted and customized. In the modeling process of input data, such the patterns would be helpful to create easily the training scenario, like as "*What should be learned as the base domain(introductory case)?*", "*Which directions should be addressed as the target domain(applied cases)?*" and "*What kinds of examples are required as the circumference knowledge?*". Moreover, from a viewpoint of reusability, it would be effective for modifying any new training scenario to build a support system based on these patterns. Therefore, if the framework technology may be considered as a design method of construction of the FEA input model and as a method of output mining, any replacement of typical frameworks is available as shown below.

(i) To discover any optimal pattern from prepared pattern catalogs → Case retrieval support,
(ii) To extract a few essential features and classify all dataset from accumulated enormous patterns → Indexing, associative learning of query words,
(iii) To show any candidates as design patterns from the cases of input model by learning the applicability of the case reusability, → The education leading a user so as to extract deep insight by oneself.

**2.4 Implementation of design pattern to knowledge base**

The knowledge offered to the users may be prepared as the similar input cases that are retrieved with query words. Accumulating these input cases into a knowledge base and providing them to the users under a specific scenario are desired. However, in order to supply any suitable cases to various demands from users, enormous support knowledge must be recorded in any database system and should be arranged, and many costs are required for its maintenance. Therefore, the reuse of such the support knowledge is expected to be any element which raises the efficiency of development for expanding the support knowledge. In order to estimate the validity of the design pattern in constructing a knowledge base, a prototype support system with the cantilever problems has been developed. This prototype system was built by using JAVA for the novices who can use MENTAT preprocessor of MARC main processor. An example of interactive screen in a web browser is shown in **Fig.4**.

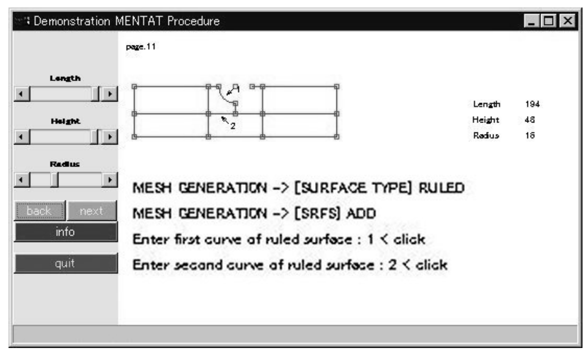


**Fig. 4 User interface of prototype system**

The support knowledge is the procedure and description based on the exercise of the input modeling to the problem of cantilever beam, here. Six cases composed of the cantilever beam, the stepped beam, the notched beam (with U or V shape), and the composite beam were prepared for exercises, and the following knowledge was described in each exercise.

- The procedures and the graphic images corresponding to them.
- Explanations of the procedure.
- The command names required for implementation of the procedure.
- Menu arrangement for the command.
- Descriptions of the command.

By handling MENTAT under instruction of training scenario, the users can learn the support knowledge. The support knowledge provided to the users is accumulated at a database, and the knowledge are extracted and displayed according to the scenario. By observing the edit procedure of MENTAT in the process of input modeling, a structural feature, as shown in **Fig.5**, was found at a design stage of the prototype system.

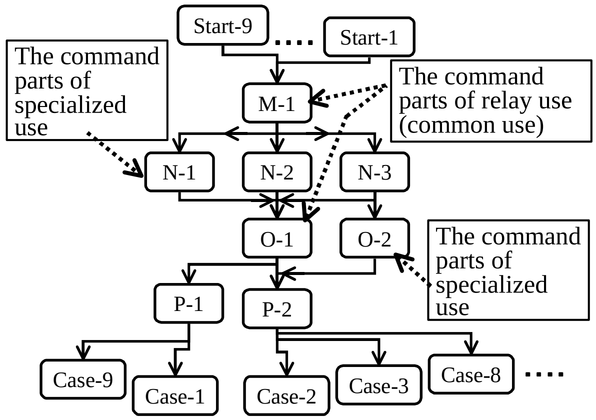


**Fig. 5 The class path of the edit procedure**

For an example, when the similar problems are considered, like a notched cantilever beam and a stepped cantilever beam, the commands which specialized in a target and the commands common to some targets exist during the first procedure to the final procedures. So that, from the view of the design pattern mentioned above, the general purpose knowledge was reused here as common parts to the two beam problems, and the peculiar knowledge was independently classified and arranged as specialization parts for each exercise. Defining a formal information amount "*Imf*" as full deployment of all procedure commands needed for supporting each exercise, and defining a real information amount "*Imr*" as unique procedure commands created actually, the compression rate of procedure information was thought as "*Imr/Imf*" here. The compression rates for command groups that are classified in the role attributes of MENTAT are shown in **Table 1**. The reusability of procedure knowledge is high when the compression rate is small. The average compression rate 0.23 was obtained for this prototype support system. From this result, it will be thought that using the technique of a design pattern to general-purpose knowledge and specialization knowledge leads to improvement in the reusability of support knowledge, and it is an effective technique for construction of a support system.

**Table 1 Result of the compression rate**

| Command Group | Rate of Comp. |
|---|---|
| MESH GENERATION | 0.45 |
| BOUNDARY CONDITION | 0.17 |
| MATERIAL PROPERTIES | 0.20 |
| LOAD DISTRIBUTION | 0.17 |
| JOB EXECUTION | 0.17 |
| Average | 0.23 |

## 3.METHOD OF EVALUATION OF ACHIEVEMENT

### 3.1 The degree vector of achievement

The authors propose the evaluation method by the degree vector of achievement as a standard to evaluate the training effect obtained by the support system. In order to support FEA modeling, the users should be trained preliminarily for the background knowledge of engineering problems and also the command operation of the application should be trained by the users. There are the following training targets, for examples.

(i) Is the basic theory of dynamics known by the user?

(ii) Does the user have numerically the geometrical knowledge for the mesh generation on a deformable area? What kinds of problem can be solve with the Finite Element Method?

(iii) Does the user know the principle of mathematical error? Why is the element dividing required?

(iv) Does the user know concretely the restriction of the plasticity and that of the elasticity?

(v) Is the magnitude of safety factor known in the design problem?

In order to evaluate metrically these training targets, it is assumed that each training target can be described with a peculiar set of the degree vectors of achievement mentioned below. The degree of achievement for a check item 'i' is defined so as to be judged from two evaluation criteria, called the rate of attendance $R_{a,i}$, and the rate of success $R_{s,i}$. They are defined as follows:

$$R_{a,i} = \frac{\text{The number of participants for the item '}i\text{'}}{\text{The number of capacities}}$$

$$R_{s,i} = \frac{\text{The number of successful candidates for the item '}i\text{'}}{\text{The number of examinees}}$$

The following evaluation functions were applied to these rates, where $R_{a,th}$ was the threshold of the rate of attendance and $R_{s,th}$ was the threshold of the rate of success.

If $R_{a,i}$ is equal to or larger than $R_{a,th}$ , then $X_{a,i}$=0.5, otherwise $X_{a,i}$=0.

If $R_{s,i}$ is equal to or larger than $R_{s,th}$ , then $X_{s,i}$=0.5, otherwise $X_{s,i}$=0.

$X_{a,i}$ is the vector component of achievement for attendance, while $X_{s,i}$ is the vector component of achievement for success. The vector component $X_i$ as the sum of these vectors is the degree of achievement for the check item '*i*'. That is,

$$X_i = X_{a,i} + X_{s,i} \quad (1)$$

where the available value of $X_i$ would be 0, 0.5, or 1. The details of these check items ($i$=1~$N$) and the threshold values are illustrated in the next section.

If a training target 'Tj' is associated with several check items, the degree vector of achievement is expressed with the set of 'Tj' as shown below.

$$\{X\}_{\mathrm{Tj}} = \{\, i \in \mathrm{Tj} \mid X_i \,\} \quad (2)$$

If $\{X\}_{\mathrm{Tj}}$ is composed of $X_1$, $X_4$, $X_7$, … $X_N$, the vector of achievement becomes the next expression.

$$\{X\}_{\mathrm{Tj}} = (X_1, X_4, X_7, \ldots X_N) \quad (2)'$$

By watching the vector component with the check item, it is possible to evaluate which teaching-material is good, acceptable, or poor. Moreover, the synthetic evaluation of the training target 'Tj' is able to do by using the normalized achievement *NA* shown in Eq. (3). Here, *m* is the number of set element for 'Tj'.

$$NA_{Tj} = \sqrt{\sum_{i \in Tj} X_i^{\,2}} \Big/ \sqrt{m} \qquad (3)$$

The training effect on a training target becomes higher as *NA* closes with 1, while it becomes lower as *NA* closes with 0 conversely. If *NA* is lower than the target value specified beforehand, it is necessary to verify whether the teaching material is suitable for the training target or not. They were tried experimentally in the following section.

### 3.2 Method of evaluation experiment

A benchmark experiment for the FEA beginners has been carried out and shown below, in order to verify the evaluation method of the achievement degree mentioned above. In the experiment, a specified rectangle data shown in **Fig.6**, is converted to a set of subdivided mesh data shown in **Fig.7**, by using both MENTAT and the prototype support system. Users learn firstly the knowledge of mesh generation by using the scenario as a teaching material displayed on the web browser, and then the users can create a set of appropriate mesh data. In order to verify the training effects on the mesh generation under the teaching scenario, the users are required to answer to all the specified questions as the check items. In the experiment, nine subjects, who were students of an engineering college but FEA beginners, had been trained. Two web textbooks as teaching material were prepared for this work as shown in **Fig.8** and **Fig.9**. Fig.8 corresponds to the textbook1 in which a full detail of the procedure is given and the necessity of the procedure is also explained, while Fig.9 corresponds to the textbook2 in which only the necessary procedure is explained. Nine problems were prepared as the check items (1) ~ (9), and they were classified into five groups 'a' ~ 'e' as the training target. They were shown in **Table 2**.


**Fig. 6 Target model for verification experiment**

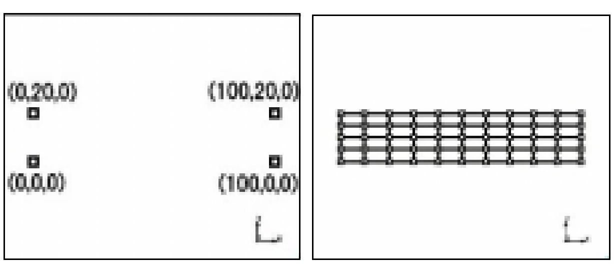


**Fig. 7 Example displays on editing for nodes and elements**

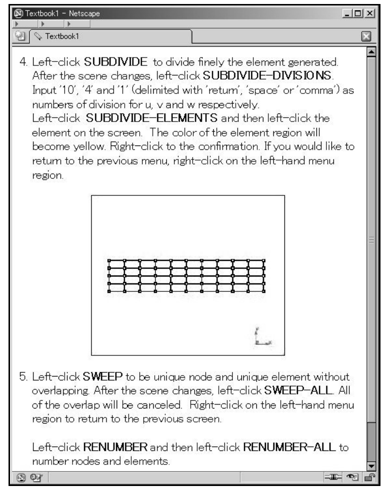


**Fig.8 A view of textbook1 as sufficient explanation**

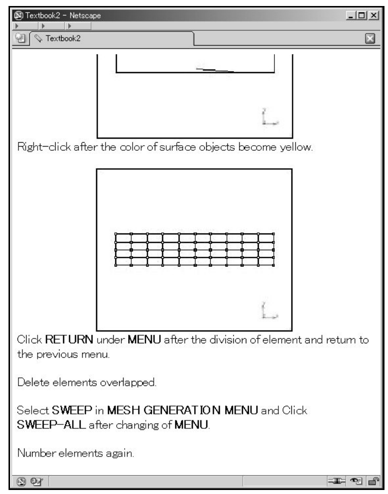


**Fig.9 A view of textbook2 as simplified explanation**

### 3.3 Result of evaluation experiment

The results of the check items obtained from the evaluation experiment are shown in **Table 3**. In this table, the success or failure were represented with "G" or "N" for all the users and all the problems. Here, the threshold $R_{a,th}$ and $R_{s,th}$ were assumed to be 0.5 respectively, and *NA* was calculated for the textbook1 and the textbook2 as the training target.

1) $R_{a,i}$: the rate of attendance for the check item '*i*'
   Since $R_{a,i}$=1 for all the item '*i*', the component of achievement became $X_{a,i}$=0.5 for all the item '*i*' in this experiment. In general, when this achievement evaluation is applied to any other teaching materials, the statistical amount of activity should be considered.
2) $R_{s,i}$: the rate of success for the check item '*i*'
   If $R_{s,i}$ is larger than $R_{s,th}$=0.5 for the item '*i*', the component of achievement becomes $X_{s,i}$ = 0.5, otherwise $X_{s,i}$ = 0.

The following matters were found from the component of the degree vector of achievement for the two teaching materials.

- For the check item (3) of 'b' judging whether the explanation is enough or not, when the textbook1 was used, $X_{s,3}$ = 0.5, while $X_{s,3}$ = 0 on the use of the textbook2. Namely, it can be judged that the textbook2 was inadequate to make all the users understand about the command FILL, however, the textbook1 were suitable for understanding the command FILL.

- For the check item (6) of 'd' judging whether the explanation is suitable or not,

  when the textbook1 was used, $X_{s,6}$ =0.5, while $X_{s,6}$ =0 by the use of the textbook2. In this case, the command CONVERT was briefly explained in only the textbook2, but that explanation did not cover the next situation and neglected what CONVERT would process. It can be judged that the users might be led to a mistake or thrown in any confusion by using the textbook2.

Hence, the supplemental explanation that helps to understand the next stage situation is necessary when the command handling is complicated. This recognition was derived from observing the component of achievement degree vector. When *NA* value of the textbook1 was compared with that of the textbook2, *NA* was 0.87 for the textbook1 and *NA* was 0.76 for the textbook2. From this comparison, it can be understood that the training effect of the textbook1 is superior to that of the textbook2. Therefore, it is found that the proposed evaluation method of achievement degree vector is available to estimate the performance of the training knowledge in an FEA support system.

**Table 2 List of the check problems**

| |
|---|
| a. The verification about the preliminary knowledge before using the teaching materials. |
| The knowledge should be mastered in advance, although the teaching materials do not explain for it. |
| (1)Which or what kinds of problem can be solved with the finite element method?<br>(2)Why is the division of elements required? |
| b. The questions for judging whether the explanation is enough or not. |
| The textbook1 explains for the procedure in a full of detail, while the textbook2 explains briefly for it. |
| (3)When is the command FILL used? |
| c. The problems what should be certainly understood by learning the teaching materials. |
| Both the teaching materials explain for this similarly. |
| (4)What is performed by the command SWEEP?<br>(7)Which or how order is correct for pointing each element? |
| d. The verification for judging whether the explanation in the teaching material is appropriate or not. |
| The procedure is explained in the textbook1, while it is not explained in the textbook2. |
| (5)Is the command SUBDIVIDE used for what?<br>(6)Is the command CONVERT used for what? |
| e. The essential knowledge about the mathematical error. |
| The knowledge is essential for thinking mathematically and numerically, but should be latent in the user's thinking even if the explanation is not given in the teaching material. |
| (8)Which pattern is correct for describing the element subdivision?<br>(9)If the meshing size is made uneven extremely, what does it happen? |

**Table 3 Result of evaluation experiment**

| All $X_{a,i}$ =0.5 ($R_{a,i}$ = 1.0) | | Check item number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | a | | b | c | | d | | e | |
| Textbook | ID | (1) | (2) | (3) | (4) | (7) | (5) | (6) | (8) | (9) |
| 1 | User1 | G | G | G | G | G | G | G | G | G |
| | User2 | N | N | G | G | G | N | G | N | N |
| | User3 | G | N | G | G | G | N | N | G | N |
| | User4 | G | N | G | N | G | N | G | G | N |
| | User5 | N | G | N | N | G | G | G | G | N |
| Rate of success $R_{s,i}$ | | 0.60 | 0.40 | 0.80 | 0.60 | 1.00 | 0.40 | 0.80 | 0.80 | 0.20 |
| $X_{s,i}$ | | 0.5 | 0 | 0.5 | 0.5 | 0.5 | 0 | 0.5 | 0.5 | 0 |
| *NA* | | 0.87 | | | | | | | | |
| 2 | User6 | N | N | N | G | G | G | N | G | G |
| | User7 | N | G | N | G | G | N | N | G | G |
| | User8 | G | N | G | N | G | N | N | G | G |
| | User9 | N | N | G | G | G | N | N | G | G |
| Rate of success $R_{s,i}$ | | 0.25 | 0.25 | 0.50 | 0.75 | 1.00 | 0.25 | 0.00 | 1.00 | 1.00 |
| $X_{s,i}$ | | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 0 | 0.5 | 0.5 |
| *NA* | | 0.76 | | | | | | | | |

## 4. CONCLUSIONS

Through the development of an FEA modeling support system, an arrangement method of the training case models based on the design pattern was proposed. By the use of the design pattern methodology based on the object orientation technology, a calculation method of the reusability and the compression rate on the supporting knowledge was derived. It was confirmed that this calculation model had a possibility to raise the reusability of support knowledge from the case analysis of the prototype support system. Moreover, the metrical model based on the degree vector of achievement was proposed, and it was shown experimentally that the training effects of any teaching materials for the training target could be evaluated by using the degree vector of achievement.

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