

# Design of a Web Site that Enable Formative Evaluation in Engineering

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## Abstract

As a result of using a formative evaluation system for basic education in engineering, 1) the percentage of students submitting reports from practical training rose 6 points from 89%, 2) the percentage of students who did sufficient preparation for examinations rose 11 points from 8%, and 3) the acceptance rate of reports on experiments rose 5 points from 88%. These improvements are a result of feedback from the evaluation.

## 1. Introduction

The objective of teaching basic subjects in physics to students who are aiming to become technical specialists is to make them understand the concepts underlying the basic processes of natural phenomena and to understand the process by which numerical formulas are derived so that they can acquire the ability to apply this knowledge. Students must acquire basic scholastic ability and self-study habits. For these purposes, a formative evaluation system that mutually links students, teaching materials and the teacher has been developed and modified several times [1][2][3].

Recently, possible utilization of the Internet as a mode of learning and as a learning support system has been studied [4]. In this paper, the design of a Web site that will enable formative evaluation in engineering subjects is discussed.

## 2. Formative evaluation system

### 2.1. Formative evaluation model

Two-way education (formative evaluation) with small student numbers is an ideal system for introducing basic engineering to students and fostering interest in science, engineering and state-of-the-art engineering techniques [5]. In the formative evaluation model, there is mutual feedback for all items of basic learning. Figure 1 shows a diagram of a formative evaluation model in which the student, teacher and teaching materials are interlinked. The content of the subject stimulates the student, and the student therefore shows interest in the subject and gains

knowledge about the subject. The teacher receives reaction information from the student through tests, and feeds back diagnostic information concerning the degree of learning achievement to the student. The teacher also uses data obtained from analysis of test items to reorganize the learning content, make improvements to test items, make new teaching materials, and determine the best sequence of learning items. Thus, the quality of information on stimulation and diagnosis is the most important factor for developing an effective system based on this model.

The construction of a database of learning items, automatic marking of tests, and processing of statistics using a personal computer has made the maintenance and further development of the system easy.

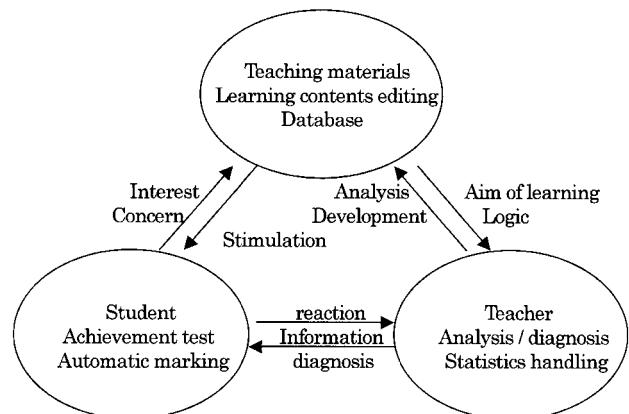


Figure 1. A diagram of formative evaluation model

### 2.2. Formative evaluation system

The features of the formative evaluation system based on the formative evaluation model are as follows. A large memory capacity is used to select, display, edit and store test items. Mark cards, automatic marking, and computer statistical processing are used for quick processing of reaction information. Appropriate analysis and diagnosis of each test using data from various statistical tables and from graphs of achievement percentage vs. caution coefficient for each student are quickly performed to generate diagnostic information.

The files comprising the formative evaluation system are shown

in Table 1. A score is inputted into a randomly accessible individual score column by automatic marking processing using a card reader [1]. Scores other than that obtained by using the card reader are inputted from file (1), (2) or (3) from main file . A file corresponding to main file is used for score list, histogram and correlation graph outputs. When the answer mark cards are automatically processed using the file containing the correct and incorrect table, a table containing data on correct and incorrect answers to examination questions, a student problem score table (SP table) [6] and a graph of caution coefficient vs. correct answer percentage are outputted. The statistical analysis-processing file is used for principle component analysis.

**Table 1.** The files comprising the formative evaluation system

Main file I	Main file II
(1) input individual score and amount table	(1) automatic marking processing
(2) input class score and amount table	(2) statistic analysis processing
(3) input score quickly	(3) caution coefficient vs. correct answer percentage figure
(4) score check	(4) questionnaire amount
(5) score histogram	(5) table on correct and incorrect answers
(6) score correlation	(6) dictionary operation
(7) display individual score	
(8) data file list	

### 2.3. Diagnostic information

The table of correct and incorrect answers shows the correct answers (as "1") and incorrect answers (as "0") for 25 test questions given by each student in a class (41 students in one class). Using this table, each student can re-learn and understand the correct answers for those questions that had been incorrectly answered. This table can be rearranged with questions shown in order of difficulty (with the easiest on the left and most difficult on the right) and the student scores shown in order from highest (at the top) to lowest (at the bottom). In the rearranged table, values of "1" are concentrated in the upper left part, and values of "0" are concentrated in the lower right part. This table is called a student problem score table (SP table). The questions are arranged in the order of high score with the students who answered correctly. In the case where there are several questions that have been answered correctly by the same number of students, the questions are arranged in the order of score with the dispersion reactions on these corresponding questions. Similarly, the students are arranged in the order of high number of correct answers. When there are students with the same scores, they are arranged in the order of the covariance reactions. A vertical line is drawn at the right of the question number that is equivalent to the score of the concerned students, counting from the left end on line about the SP table and call the line joined these S curve.

Next, students to whom attention should be given can be identified by comparing the perfect pattern that becomes "1" on the left side and "0" on the right side of the S curve with the actual reaction pattern. When the covariance on the number of the correct answer students with the question and the perfect reaction pattern is compared with the covariance on the number of correct answer students with the question and the actual reaction pattern, the index that evaluates the comparison size relatively is used. This index is called the caution coefficient of the student and is calculated by

$$\left( \text{Caution coefficient of student } i \right) = 1 - \frac{\left( \text{Covariance on reaction pattern of student } i \text{ and the number of the correct answer students with question} \right)}{\left( \text{Covariance on complete reaction pattern about the point of student } i \text{ and the number of the correct answer students with question} \right)}$$

$$= \frac{\left( \text{Summation of the number of the correct answer students with mistake answered question on the left side of the S curve} \right) - \left( \text{Summation of the number of the correct answer students with correct answered question on the right side of the S curve} \right)}{\left( \text{Summation of the number of the correct answer students with question on the left side of the S curve} \right) - \left( \text{Score of student } i \right) \times \left( \text{Number of the average correct answer students} \right)}$$

The caution coefficient is 0 for a student who has a perfect pattern and increases as the reaction pattern becomes more dispersed. The caution coefficient would be larger than 1 for the unusual case of a student who has incorrectly answered relatively easy questions and correctly answered relatively difficult questions. The graph of caution coefficient plotted against correct answer percentage for a student provides diagnostic information on various aspects of the student's learning, such as whether the student 1) had studied sufficiently, 2) was careless in answering questions, 3) not prepared sufficiently for the test, and 4) has acquired basic knowledge. This diagnostic information is useful for preparing the next test.

## 3. Evaluation of the physics subjects

### 3.1. Physics subjects and ratios of practice prints, examinations and experiments used in physics classes

Practice prints, examinations and experiments conducted by students have been used to evaluate physics subjects. Table 2 shows the number of students, the number of practice prints used in the class, the number of examinations given and the number of experiments conducted by students in each engineering class for each year from 1995 to 1999. Until 1995, basic textbooks and short tests had been used, but these were replaced by practice prints from 1996. The ratios of practice prints, examinations and experiments after 1996 were about 25%, 40% and 35%, respectively.

**Table 2.** The number of students, practice prints, examinations and experiments in each engineering class from 1995 to 1999

Engineering class	'95 (Heisei 7)				'96 (Heisei 8)			
	students	print	exam.	experiment	students	print	exam.	experiment
Mechanical	39	*	2(4)	13	43	13	3(4)	12
Electricity	44	*	6	13	42	29	6	12
Electronic	42	*	6	11	40	29	6	13
Information	42	*	6	13	45	29	6	13
Architecture	43	*	6	12	41	29	6	13
class	'97 (Heisei 9)				'98 (Heisei 10)			
	students	print	exam.	experiment	students	print	exam.	experiment
Mechanical	44	13	5(4)	13	39	12	4(3)	10
Electricity	41	29	6	11	41	27	6	13
Electronic	41	29	6	12	41	27	6	13
Information	39	29	6	12	43	27	6	12
Architecture	41	28	6	12	41	27	6	12
class	'99 (Heisei 11)				* mark in '95 (Heisei 7)			
	students	print	exam.	experiment	Used text of collecting problems and did small tests. The number in the brackets is times of the examination by the other charge teacher.			
Mechanical	40	13	4(2)	13				
Electricity	39	28	6	11				
Electronic	42	29	6	12				
Information	40	29	6	11				
Architecture	41	29	6	13				

The practice prints, examinations and experiments are closely interrelated. The aims of the practice prints are to confirm that the students have learned basics and to help the students to establish regular study habits. Each student's knowledge of basics is also tested in examinations and experiments. The ratios of practice prints, examinations and experiments used in each class depend on the attitude of students toward learning, the quality and quantity of teaching materials, and views of the teacher on education.

### 3.2. Practice prints

Until 1995, class time was allotted for students to do practice problems using a book of basic problems. However, this system changed in 1996. In the present system, practice prints are made by the teacher using textbooks B and published by Suken, and one print is given to each student after every 2-3 hours of lecture time. The students answer the questions in the print in their own time and submit the prints to the teacher in the next class.

Since this system was started in 1996, efforts have been made every year to improve the quality of the prints. Table 3 shows the 29 subjects tested in the practice prints in 1999 and the periods in which they were given to students. About six questions are given for each subject. Two of these six questions are on definitions of terminology, which is explained in lectures. The other basic questions can be answered in about 20 minutes.

**Table 3.** Subjects and periods of practice prints.

1 passage of the light	16 inner energy and specific heat of gas
2 interference, diffraction and spectrum of the light	17 magnetic field which electric current is formed
3 static electric force and static electric induction	18 force which the electric current receives from the magnetic field
4 electric field, electric potential and potential difference	19 Lorenz force
5 electric capacity	20 electromagnetic induction
6 law of Ohm	21 self induction and the mutual induction
7 direct current circuit	22 alternating current 1
8 electric current and work	23 alternating current 2
9 electron	24 resonance and electric vibration
10 radiation line and its nature	25 electromagnetic wave
11 movement and power product	26 particle of the light
12 uniform velocity circle movement and inertia force	27 wave motion of electron
13 single vibration	28 atom and nucleus
14 gravitation	29 nuclear energy
15 gaseous law and molecule movement	No.18~24 (~until Dec.)
No.1~6 (April to June)	No.25~29 (~until Feb.)
No.7~17 (~until Sept.)	

**Table 4.** The submissive situation of practice prints from 1996 to 1999

	'96	'97	'98	'99
total numbers	5431	5229	4950	5179
submission %	85.29	85.64	86.61	91.79
delay %	3.96	5.53	7.47	2.9
no submission %	10.75	8.83	5.92	5.31

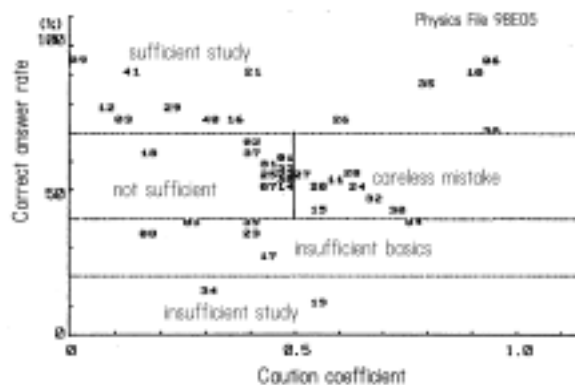
In case of presenting print answer, we point out the answer paper that have no process of the computation, the blank of answer columns and the mistake answer part, we make these points correct. These prints are expected to provide useful data for individual student evaluation. Table 4 shows the percentages of students who submitted prints on time, those who submitted prints at least 2 months late and those who did not submit prints for each year from 1996 to 1999. The total percentage of students who submitted prints (on time or late) increased by 6% from 89% during the 4-year period, while the percentage of students who did not submit prints decreased in the same period from 11% to 5.3%. Many of the students who were late in submitting prints submitted them just

before or after re-examinations. The annual decrease in the percentage of students who did not submit prints indicates an improvement in study habits of the students.

### 3.3. Examinations

Examinations are given 6 times a year: twice in the first half of the first semester, twice in the latter half of the first semester, and twice in the second semester. Each examination consists of 5 or 6 problems with a total of 25 questions. Answers are given on mark cards. Each exam also includes questions that require explanatory answers, filling in blanks in formulas, and filling in parts of graphs, and the answers to these questions are marked by the teacher. The mark cards are processed by computer and each student is given a graph showing student scores plotted against caution coefficient and an SP table after each examination.

An example of a graph showing student scores plotted against caution coefficient is shown in Figure 2. Each number in this figure is the number given to a student. The students are divided into the following six groups according to the examination score and caution coefficient (CS): one group with examination scores  $> 70$ , indicating that sufficient study had been done (group A); one group with examination scores  $\geq 40$  and  $< 70$  and CS  $\geq 0.5$ , indicating that careless mistakes had been made (group B); one group with examination scores  $\geq 40$  and  $< 70$  and CS  $< 0.5$ , indicating that preparation for the examination had not been sufficient (group C); one group with examination scores  $\geq 20$  and  $< 40$ , indicating insufficient knowledge of basics (group D); and one group with examination scores  $< 20$ , indicating insufficient study (group E).



**Figure 2.** Student scores plotted against caution coefficient

**Table 5.** The preparatory condition for the exam from 1995 to 1999

	'95	'96	'97	'98	'99
corresponding total no.	1104	1137	1192	1152	1132
enough study %	9.15	7.92	13.84	18.92	14.31
careless mistake %	5.62	4.93	9.98	9.64	9.1
not sufficient %	29.8	27.7	26.43	32.99	25.09
insufficient basics %	33.79	36.24	29.95	25	33.84
insufficient study %	20.2	21.46	18.12	12.33	16.17
no receive exam. %	1.45	1.76	1.68	1.13	1.5

Table 5 shows the total number of students who took examinations and the percentage of students in each of the above six groups for each year from 1995 to 1999. As can be seen in the table, the percentage of students in the group of students who had

studied sufficiently increased, while the percentages of students in the group of students with insufficient knowledge of basics and in the group of students who had not studied sufficiently decreased during the 5-year period. The results shown in this table indicate that there had been an overall improvement in the level of preparatory study for examinations from 1996 to 1998. In the period from 1996 to 1998, the total percentage of students in groups A and B (the top two groups) increased from 13% to 29%, the percentage of students in group C (middle group) increased from 28% to 33%, the percentage of students in group D decreased from 36% to 25%, and the percentage of students in group E (the lowest group) decreased from 21% to 12%. However, the level of preparatory study for examinations decreased in 1999 to almost the same level as that of 1997. The main reason for this decline is thought to be the method used by most students for solving difficult problems in the prints (see section 5.1). Continued efforts must therefore be made to raise this level by improving the practice prints and returning evaluation sheets of examination results to the students as quickly as possible.

### 3.4. Experiments

Experiments are conducted by students in the second year of study after instruction on the experiments has been given to the students. Due to the large number of students, the experiments are conducted on a rotation basis. In 1999, experiments were conducted by students on the following 13 subjects: dynamics (measurement of water surface tension, moment preservation law, measurement of inertia moment), light (wavelength measurement), heat (measurement of the specific heat of a solid, measurement of the specific heat of water), electricity (measurement of electrostatic capacity, whetstone bridge, circuit meter), magnetism (measurement of flux density, measurement of  $e/m$ ), and computers (simulation, automatic control).

Five of the abovementioned experiments (measurement of water surface tension, whetstone bridge, circuit meter, simulation, and automatic control) were each conducted by one student, and the other eight experiments were each carried out by two students. The students were instructed to submit reports on each experiment within three days after completion of the experiment. Each report was scored according to attitude of the student toward the experiment, presentation of tables in the report, clarity of values in formulas, presentation of graphs, and answers given to questions.

Table 6 shows the total number of students who conducted experiments and the percentage of students in each of the following five groups for each year from 1995 to 1999: a group of students who submitted reports within 3 days and whose reports were accepted upon first submission (group A), a group of students who submitted reports within 3 days but were instructed to re-submit the reports after making some revisions (group B), a group of students who submitted reports at least 2 months late (group C), a group of students who re-submitted reports but whose re-submitted reports were not acceptable (group D), and a group of students who did not submit reports (group E). As can be seen in the table, the total percentage of students in groups A and B (students who took a serious attitude toward the experiments) increased from 85% in 1995 to 90% in 1998. The total percentage of students in groups C, D and E (students who did not take a serious attitude toward the experiments) decreased from 15% in 1995 to 10% in 1998 but increased again in 1999 to almost the same percentage as that in

1995. The percentage of students in group D decreased dramatically from 8% in 1995 to 3% in 1998. Almost all of the students submitted reports in the period from 1997 to 1999 (average total percentage of students in groups A-D: 96%). The reason for the increase in the percentage of students who did not take such a serious attitude toward the experiments (groups C, D and E) is thought to be the method used by most students for solving difficult problems in the prints (see section 5.1) and limitation to the time for use of the laboratory to conduct experiments.

**Table 6.** Submissive situation of experiment reports from 1995 to 1999

	'95	'96	'97	'98	'99
Total numbers	2603	2658	2475	2464	2426
first submission %	48.64	52.48	55.76	45.74	53.75
re-submission %	36.42	31.08	33.82	43.99	31.99
delay %	2.57	4.14	2.34	3.25	5.81
not accept %	7.76	7.71	5.17	3.08	4.29
no submission %	4.61	4.63	2.91	3.94	4.12

## 4. Data used for evaluation

Three types of tables of data to be used as a basis for evaluation were prepared: 1) a table of data on practice prints in which students were divided into groups of those whose prints had been accepted on first submission, those whose prints had been accepted on re-submission after revision, those whose prints had not been sufficiently revised, those who were late in submitting prints, and those who did not submit prints; 2) a table of correctly and incorrectly answered questions for each examination; and 3) a table of data on reports concerning experiments in which students were divided into groups of those whose reports had been accepted on first submission, those whose reports had been accepted on re-submission after revision, those whose reports had not been sufficiently revised, those who were late in submitting reports, those who did not re-submit reports, and those who did not submit reports. These data are used to evaluate students, teaching materials and teaching improvements.

## 5. Evaluation of students by questionnaires

### 5.1. Questionnaires on practice prints

Questionnaires on practice prints were given to 199 second-year students in November 1999. Each questionnaire consisted of four questions on 1) the level of difficulty of the prints, 2) time taken to complete one print, 3) ways of solving difficult problems, and 4) usefulness of the prints (as reviews, summaries, application problems, etc.). For the first question, 2% of the students answered "easy", 20% answered "appropriate", 44% answered "somewhat difficult" and 33% answered "difficult". For the second question, 49% of the students answered "less than 30 minutes", 23% answered "30-40 minutes", and 28% answered "more than 40 minutes". For the third question (for which more than one answer could be given), 75% of the students answered "asking friends", 27% answered "checking in books at the library", 26% answered "copying the answer from a friend's print", 5% answered "leaving

unanswered", and 11% answered "asking the teacher". The results for the second and third questions are shown in Figure 3.

To fix the basic item, each student should answer alone to the practice, and is suitable for about 30 minutes to spend on it. Efforts must be made to try to reduce the percentages of students who answered "difficult" for the first question and "more than 40 minutes" for the second question to zero. Although a large percentage (75%) of students answered "asking friends" for the third question, it is likely that many of those students in fact simply copied the answer from a friend's print, and this is thought to be one of the reasons for the decline in the level of preparatory study done for examinations in 1999. These questionnaires are thought to be a useful means for matching between the intention of the teacher and the correspondence of the student.

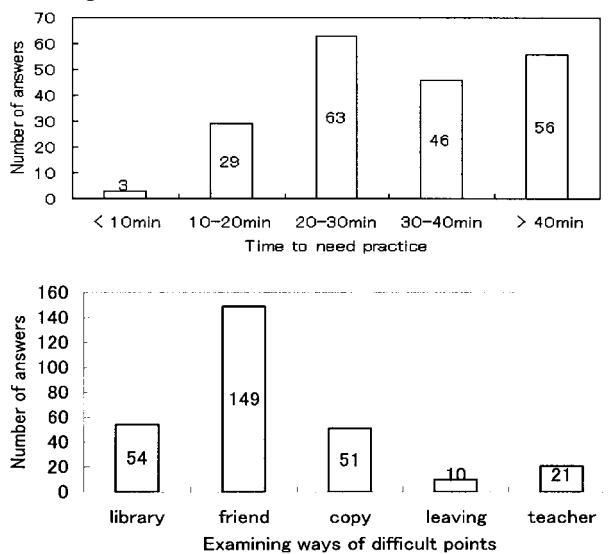


Figure 3. Time taken practice and examining ways of practice problems

## 5.2. Questionnaires on experiments

Questionnaires on experiments were given to 159 second-year students on December 2, 1999. Each questionnaire consisted of four questions. The first question was on the time taken to write reports. For this question, 19.5% of the students answered "less than 2 hours", 44% answered "2-4 hours", 20.1% answered "1 day", 11.3% answered "2 days", and 3.8% answered "3 days or longer". The second question was on ways of solving problems when writing the reports. For this question (for which more than one answer could be given), 66% of the students answered "checking in books at the library", 78% answered "asking friends", 17.6% answered "copying from a friend's report", 3.8% answered "leaving unsolved", and 8.8% answered "asking the teacher". The third question was on points given attention to when writing the reports. For this question (for which more than one answer could be given), 32.1% of the students answered "correct use of units of measurement", 37.1% answered "presentation of graphs", 44% answered "clear presentation of values in formulas", 28.3% answered "calculation of errors", 47.8% answered "answering all of the questions given", and 6.9% answered "writing neatly". The results for the first and second questions are shown in Figure 4.

Most of the students (83%) were able to complete a report in less than one day. The remaining 17% of the students included those who did not submit reports and those whose reports were not

acceptable. Although it was notable that a high percentage of students (105/159) who answered that they checked in books at the library to solve difficult problems when writing reports, a high percentage of students (78%) also answered that they asked friends to help them solve difficult problems when writing reports, and it is likely that many of those students in fact simply copied from a friend's report, which is thought to be one of the reasons for the increase in the percentage of students who did not take a serious attitude toward experiments in 1999. A notable point in the answers given to the third question is that 30-40% of the students paid attention to all points when writing reports.

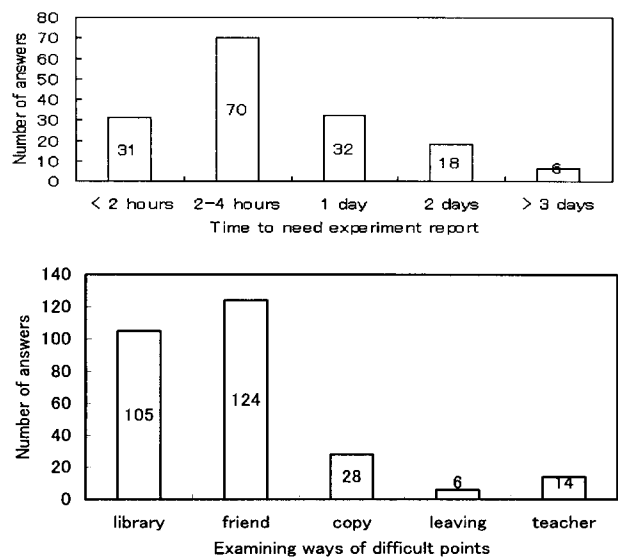


Figure 4. Time taken the report and examining ways of difficult points

In the fourth question in the questionnaire on experiments, the students were asked to list the experiments that most impressed them (and the aspects of the experiments that were impressive). The top five experiments (and the aspects of those experiments that were impressive) given by the students were 1) measurement of surface tension (being able to observe changes in tension when a Jolly's spring balance was used), 2) automatic control (the ability of a computer to judge a situation), 3) measurement of the e/m ratio of electrons (being able to observe and control movement of electrons), 4) measurement of wavelengths of light (diffraction images of reflected light on the graduation surface of a stainless steel measure), and 5) simulation (visualization and graphical display of a phenomenon). The same five experiments were also selected by students, although in different order, in questionnaires given in 1998. The reason for the same 5 experiments being selected as the five most-impressive experiments by students in both 1998 and 1999 is thought to be a reflection of the surprise at, interest shown in the scientific process of, observation of the phenomenon changing and consideration of the physical quantity changing.

## 6. Design of a Web site

### 6.1. Points to give attention to in the design of a Web site

Practical exercises, examinations and experiments are important for students to learn the basics of engineering, and the importance of each of these as well as their interrelationships have been extensively studied. From these points of view, some points that

should be given attention when designing a Web site for formative evaluation are as follows:

1. Knowledge of the level of the students
2. Check of submissive situation of the practice reports and the feedback of evaluation
3. The difficult degree of the practice is better easy than difficult
4. Required time for completion of the print of 30 minutes
5. Organization of questions into review, summary and application sections
6. Use of pictures, figures and tables to show phenomena and theory
7. Feedback information on marked prints

Efforts should be made to improve the quality of stimulation information and reaction information with consideration given to the above items.

## 6.2. Content of the Web site

The Web site will include a home page, table of contents for each item, a page displaying types of practice problems, a page of questions, a page for answering the questions, and a search page. Attention should be given to links between pages and folder design in order to make the site easy to use [7].

## 7. Conclusions

Efforts to make basic engineering subjects appealing to students and to create an atmosphere that encourages students to ask questions are needed. When a student asks the teacher a question, it is important for the teacher to try to make the student understand at what point in the student's thought process the mistake has arisen. By doing this, the student will be able to understand the elements making up the phenomenon and understand the process by which numerical formulas are derived. Such an approach by the teacher should encourage the student to take a serious attitude toward study.

All students want to know the results of examinations as soon as possible. Information on the results of an examination, including a table of correctly and incorrectly answered questions and a caution coefficient graph, will help the students plan for the next examination. The teacher should also make appropriate changes to examinations and make efforts to improve the quality of lectures and to make time to listen to and advise students. A system for the development and evaluation of scholastic ability in which the Web site can be accessed from any classroom through the Internet is needed.

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