The Effects of Computer-Assisted Learning in Teaching Permanent Magnet Synchronous Motors

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Abstract—This research compares the use of computer-assisted learning (CAL) with the traditional learning methods in the teaching of permanent magnet synchronous motors (PMSMs). The present study was performed on an experimental group consisting of 16 students and a control group consisting of 15 students. In order to measure the students’ success, a multiple-choice test of 23 items was used as the pretest and the posttest. The results show that the CAL method was more effective in increasing student success than the traditional method. An attitude scale of 17 items was applied to measure the attitudes of the experimental group students and a positive attitude towards CAL was found.

Index Terms—Computer-assisted learning (CAL), fuzzy control, permanent magnet motors, proportional-integral-differential (PID) control.

I. INTRODUCTION

Computer-assisted learning (CAL) is a method used to increase the efficiency of traditional educational approaches (lectures, exercises, and laboratories). CAL is used in a great number of applications in education and training. CAL is particularly useful in challenging topics, such as electrical machines [1]. The simulations used in this study are a type of computer-assisted instruction (CAI). Simulations provide a model in which the student plays a role and interacts with the computer. Simulations have most often been used in higher education to model scientific processes. They are applicable to any field, however, and can be of significant help in illustrating concepts, in helping students to develop problem solving techniques, or in allowing students to explore complex interactions [2].

Simulation instrument development requires expertise in computer programming, and is very time consuming. Those who work in this field use the well-known PSPICE and Matlab software programs as their professional tools. In this study, the Matlab/Simulink software program was used to implement the CAL.

In an electrical machines course, the curriculum topics are essentially electrical motors and transformers. In traditional education, electrical machines are learned through regularly studying the chosen textbook, attending classes, taking notes and doing some practical work in the laboratory. CAL is an instructional method which can be used to teach the content and practice of an electrical machines course. The advantages of CAL include an improvement in learning, a reduction of the learning time period and the development of quite positive attitudes towards CAL by the students [2]. According to some studies made in recent years, additional advantages of CAL are the achievement of activity-based teaching, the promotion of active learning, the enrichment of students by collaborative learning and the encouragement of students towards independent learning [3]–[5]. One of the goals of a university engineering education is to develop a student’s creative skills to prepare them to perform effectively as engineers. Various studies examining the use of CAL in engineering education have suggested that it would be an effective medium for this purpose [1], [6]. The use of CAL in an introductory computing class for engineers has been shown to lead to more effective student learning, with the students gaining a deeper understanding by using a multimedia textbook than by using a traditional paper-based counterpart [1], [6]. Cairncross and Mannon [7] illustrate similar success for a CAL package designed for electronic engineering students.

In another subject area Morgil et al. [8] compared the traditional and CAL methods in teaching the topic of acids and bases in chemistry lectures. According to the pretest results, the success rates of the experimental group students increased by 52% on average, compared to only 32% in the control group students, which is a significant difference in favor of the experimental group. The evaluation of the posttest results showed that the average score of the control group was 68% compared to 80% in the experimental group. Chang et al. [9] proposes a computer-assisted system named MathCAL, whose design is based on four problem-solving stages: understanding the problem, making a plan, executing the plan, and reviewing the solution. A sample of one hundred and thirty-five grade elementary school students completed a range of mathematical problems; the results showed MathCAL to be effective in improving the performance of students with lower problem-solving ability.

In the area of electrical motors and CAL, Fardanesh [10] developed an interactive graphical software package program to enhance the teaching of electrical motors. The main objective of this tool is to increase students’ understanding the operation of rotating electrical machines. Kyranastasis [11] presents the contributions of a target-specific instructive simulator to learning, which can be used by teachers (during classroom lectures) or by the students (in the laboratory before real laboratory applications or when studying by themselves at home). Simulations of the main features of four different types of electrical motors are provided. Kikuchi et al. [12] developed a permanent magnet step motor simulation to be used in college classes. This program is offered as a useful tool for practical mechatronic applications. Akcayol et al. [13] present a flexible instructional...
tool for brushless DC motors which is controlled by fuzzy logic. Mazo et al. [14] present instructional material developments in motor control in the Electronics Department of Alcala University, Madrid, Spain. Kikuchi and Kenjo [15] developed main and supporting computer systems for remote control of small powerful step motors. Via computer a student at a distance can use audio and visual means to control small powerful step motors. Yeung and Huang [16] developed a remote-access control system which allows users to enhance their control experience via the Internet, with a DC motor control module being used as an example. Li and Challoo [17] emphasize that, presented by means of the traditional learning approach, an electrical machines course is evaluated as old-fashioned and unexciting by the students. They state that this negative situation seriously restricts student learning, and that computer-assisted teaching offers a new approach to the presentation of the subject.

In the area of electrical and electronic engineering and CAL, Cvetkovic et al. [18] developed CAL programs to convey the fundamental concepts of electrical engineering and to teach signal analysis, theory of electromagnetic fields, engineering mathematics, power electronics, and telecommunications lessons. Ringwood and Galvin [19] developed and evaluated a CAL package for artificial neural networks which forms an undergraduate course. Parido et al. [20] present a CAL tool to design and develop digital electronic circuits, and to test the developed circuits. The system, called VISCP, is described as an instructional tool used for the practical work on digital systems and for the practical design of basic digital circuits. Wagner [21] states that in parallel with the increase in computer use, visual classrooms, and visual laboratories are becoming more common. Based on these visual classrooms and visual laboratories, the projects tutorial system for programmable logic controller (TESS), multimedia consulting system for cordless drill driver (MILAS), and visual automation laboratory (VAL) were developed. Ilango and Doulai [22] present an interactive learning package developed for electrical engineering courses in the University of Wollongong, New South Wales, Australia, and mention that CAL plays an increasing supporting role to the traditional learning approaches. Pullen and Mercer [23] developed a CAL system to solve electrical engineering problems and observed improved academic performances by students who used the system. The restructuring of courses in power electronics and electronic machines drives in the University of Minnesota, Minneapolis, was described by Mohan in [24], where digital control was integrated into entry-level courses. Students in these courses were motivated to take related courses in programmable logic controllers, microcontrollers and digital signal processor applications.

The study presented in this paper investigated both the effectiveness of CAL, and the students’ attitudes towards CAL, in the teaching of permanent magnet synchronous motors (PMSMs) and the control of these motors. The fundamental hypothesis of this research was that the integration of CAL in an electrical machines course on PMSMs and their control would have a significant effect on student success. From this hypothesis it follows:

1) significant differences were not expected between the pretest scores of the experimental and control groups;
2) significant differences were expected between the posttest scores of the experimental and control groups;
3) significant differences were expected between the pretest and posttest scores of the experimental group;
4) significant differences were expected between the pretest and posttest scores of the control group.

A further research question was to elicit student attitudes towards CAL.

II. METHOD

The research compares the performance of an experimental group, taught using CAL, with that of a control group, taught by traditional methods. This comparison was made in the subject area of PMSMs and their control of special electrical machines. Special Electrical Machine is a class taken in the seventh semester of a students’ degree, during their fourth year with the Technical Education faculty. The topic covers hysteresis motors, step motors, brushless DC motors, PMSMs, switched reluctance motors, and servo motors and their control. The functions of these motors are the same, but their structures, controls, driver setups and feeding voltages are different. PMSMs and their control have been chosen as the research subject across these areas due to its current importance. The subject of special electrical machines is divided into two modes: the structure of the motor as Mode I, and its control as Mode II. Mode I includes: basic structure of PMSMs, torque-angle characteristic, voltage, current, and speed equation sets. Mode II includes: the speed control of PMSMs, proportional integral (PI) controller structure, fuzzy logic controller (FLC) structure, and speed analysis of the motor unloaded, under load, and step load. The first step in integrating CAL was the preparation of a worksheet by a curriculum development expert, a measurement and evaluation expert, and a subject area expert. The worksheet lists the lesson name, the unit name (PMSMs and their control) and lists the learning objectives. Examples of the learning objectives are: 1) to acquire knowledge of the PMSMs’ mathematical model; 2) to recognize which sort of speed control is appropriate for a given mathematical model; 3) to be able to control the speed of the motor with PI and fuzzy logic controllers when unloaded, loaded, and step loaded; and 4) to compare the speed values obtained from control of the motor with PI and fuzzy logic controllers when unloaded, loaded, and step loaded. Desired experimental techniques are also listed on this worksheet. In order for the students to acquire these experimental techniques, the subtopics of the PMSMs’ mathematical model, FLC structure, the PI controller, and speed control were studied in the computer laboratory on a Windows XP Pro operating system using the Matlab/Simulink program (Matlab 7.0.4, 2005). The operating procedure for these subcategories was written in order, entered into the computer, and the students were asked to implement these with the assistance of the computer. A certain time was given for each step of the operation. Some examples related to the operating procedure are given in Appendix A. The students were also asked to make a performance analysis of the PI controller and the FLC and to compare these.

The CAL method required more instructor preparation time than the traditional method. The traditional method instruction times are two 45-minute lessons each week for seven weeks; 14 lessons in total.
In the CAL group, each student was given a computer. Short explanations about what to do were given to the students at the beginning of the lesson. They were given information about CAL and watched and guided while working with the computer. In the meantime, their questions were answered and assistance was given when required. The syllabus for Mode I and Mode II follows.

Mode I:
Week 1: The students studied the structure of PMSMs with an animation written in Flash. They studied a Matlab/Simulink model file that contains the PMSMs’ mathematical model block and closed loop speed control block.
Week 2: Current, voltage, torque, and speed function blocks were created inside the PMSMs’ mathematical model block. The equations necessary for the mathematical model were contained in the PMSMs’ mathematical model block shown in Fig. 1.

As an example, an explicit expression of the block, which is a subsystem of the PMSMs’ mathematical model shown in Fig. 1, is given in Fig. 2 as a Matlab function block. In the block, axes have been converted into axes.

Mode II:
Week 3: PI control of the PMSM is achieved. Students created the PI controller block diagram seen in Fig. 3 within the controller block in Fig. 1. In addition, they examined the impact of a change in Kp and Ki coefficients on the system. In Fig. 3, the Kp proportional coefficient and the Ki integral coefficient are expressed and these coefficients are determined by trial and error.

Week 4: The input, output variables, and rule base of FLC were defined in the Matlab/Simulink fuzzy inference system editor.
Week 5: The PMSM was controlled with fuzzy logic. The students created the fuzzy logic structure seen in Fig. 4 and activated it within the controller block.
Week 6: The students used both the PI and FLC in speed control of the PMSM.
Week 7: The rise time, steady state error, and overshoot were examined in speed graphs obtained in loaded, unloaded, and step-loaded conditions of the motor, and performance analysis was conducted.

In this study, as is generally seen with the integration of CAL, the instructor took the role of an advisor rather than a teacher, and spent more time addressing the problems of students working individually than in lecturing [28].

In the traditional instruction method topics were addressed in the same order as in the CAL program. The textbook [25]–[27] and the blackboard were used during the lesson. The subject was explained in the abstract, in accordance with the unit objectives.

The syllabus was as follows.
Mode I:
- Week 1: The closed loop structure of PMSMs was taught using figures given in textbooks, and closed loop speed control was taught by drawing on the blackboard.
- Week 2: The current, voltage, moment, and speed equations of the mathematical model of PMSMs and their interconnections were taught by drawing on the blackboard.

Mode II:
- Week 3: The mathematical expressions of the PI controller block diagram were given. Drawing on the blackboard was used to explain that the Kp and Ki coefficients could be determined by trial and error, and the impact that changes in these coefficients could make on the system.
- Week 4: The input and output variables of FLC were explained and the creation of rule base was expressed on the blackboard.
- Week 5: The FLC structure was explained by drawing this on the blackboard as a block diagram.
- Week 6: Graphs of the speed of the motor in loaded, unloaded, and step-loaded conditions, obtained through PI and fuzzy logic controllers were drawn on the blackboard, and rise time, steady state error and overshoot concepts were explained.
- Week 7: The PI and fuzzy logic controllers were compared in terms of speed control, and their performance was analyzed.

In both methods the lesson was given by the same instructor (the first author of this paper). Learning objectives for both methods were identical. Both groups (CAL and traditional) spent identical periods of time in the classroom. For the two groups, times spent studying outside the classroom were assumed to be identical.

A. Participants

The data in this research were collected from 31 students registered in the Special Electrical Machines class. These students were the senior students of the Technical Education faculty of Kocaeli University, Kocaeli, Turkey. The Technical Education faculty has a four-year bachelor’s degree program. Those graduating from here can be assigned as teachers in vocational and technical education high schools or work in industry. The previously mentioned students were registered in the electrical education programs. The following method was used to select the experimental and control groups. First, the average of all of the scores the above-mentioned senior students had achieved during the previous three years was calculated, and their numerical scores in the university entrance exam (the state-held university entrance exam) were obtained. Then the students were divided into two separate groups according to their numerical scores, average of scores, age and gender. The learning method to be applied to each group was randomly selected. The number of students in the experimental group was 16, with an average age of 22. The number of the students in the control group was 15, also with an average age of 22.

B. Instruments

Thirty-four items were selected from the topic of PMSMs and their control in the Special Electrical Machines class in order to develop an experimental multiple-choice test of 24 items. Each item was assigned a key according to the objectives of the relevant unit. Each item had one correct answer. These 34 items were prepared using the methodology suggested by different authors in the educational measurement field [29]–[32]. The prepared items were examined by experts (a professor and an assistant professor in the field of education) separately. These items were answered independently and verbally by three students similar to, but not members of, the research groups. After these verbal responses and the expert reviews no need was felt to eliminate any of the items, but some items were corrected. The 34-item test was applied to a preliminary trial group of 41 students, selected from the student body, who resembled the research groups so as to allow item statistics (item difficulty, item test correlation) to be determined. Based on the results, a 23-item experimental test was developed. Each item consisted of one point. Examples are given in Appendix B. In addition, an attitude instrument was developed to determine the students’ attitudes towards CAL, which consisted of 24 items with a Likert scale of choices (strongly agree–5; agree–4; undecided–3; disagree–4; strongly disagree–1). A similar method to the one used for the above-mentioned success test was followed. 24 statements, half of them positive and the other half negative, designed to elicit the attitude towards the CAL method were written. These statements were given to two education experts (a professor and an assistant professor) to evaluate independently, and were also given to two students (not in the research groups), after which some items were corrected. The 24-item attitude instruments was first given to a group similar to the main group of this research whose members were enrolled in the Special Electrical Machines course (senior grade students also enrolled at the same program), after which a final survey of 17 items was generated.
TABLE I
STATISTICAL ANALYSIS OF PRETEST AND POSTTEST SCORES OF THE EXPERIMENTAL AND CONTROL GROUPS

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group (N=16)</th>
<th>Control Group (N=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>Mean</td>
<td>5.50</td>
<td>13.81</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.39</td>
<td>0.56</td>
</tr>
<tr>
<td>Median</td>
<td>5.00</td>
<td>13.50</td>
</tr>
<tr>
<td>Mode</td>
<td>4.00</td>
<td>13.00</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.54</td>
<td>2.22</td>
</tr>
<tr>
<td>Variance</td>
<td>2.40</td>
<td>4.96</td>
</tr>
<tr>
<td>Range</td>
<td>5.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.00</td>
<td>10.00</td>
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<tr>
<td>Maximum</td>
<td>8.00</td>
<td>18.00</td>
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</tbody>
</table>

TABLE II
STATISTICAL RESULTS OF THE PRETEST SCORES OF EXPERIMENTAL AND CONTROL GROUPS

<table>
<thead>
<tr>
<th>Groups</th>
<th>Test</th>
<th>N</th>
<th>( \bar{x} )</th>
<th>ss</th>
<th>sd</th>
<th>t</th>
<th>P</th>
<th>MWU</th>
<th>z</th>
<th>P</th>
<th>Row Average</th>
<th>Row Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp.</td>
<td>Pre</td>
<td>16</td>
<td>5.50</td>
<td>1.54</td>
<td></td>
<td>-0.90*</td>
<td>0.375</td>
<td>94.50</td>
<td>-1.02</td>
<td>0.305*</td>
<td>17.59</td>
<td>281.50</td>
</tr>
<tr>
<td>Control</td>
<td>Pre</td>
<td>15</td>
<td>4.93</td>
<td>1.94</td>
<td></td>
<td>-0.09</td>
<td>0.93</td>
<td>94.50</td>
<td>-1.02</td>
<td>0.305*</td>
<td>14.30</td>
<td>214.50</td>
</tr>
</tbody>
</table>

\( P^* > 0.05 \)
\( P^* > 0.05 \)

III. RESULTS

The mean, standard error, standard deviation, and mode, median, minimum, and maximum scores of the pretest and posttests of each of the experimental group and the control group are displayed in Table I.

The results of the independent samples t-test and the Mann–Whitney U test on the average pretest scores of the experimental group and the control group students are given in Table II. The independent samples t-test suggests the difference between the groups is not significant (\( t = -0.90, s = 29, P > 0.05 \)). Since the sample size was small, the Mann–Whitney U test was also conducted. The results of this test also show no significant difference between the groups (\( z = -1.02, P > 0.05 \)), verifying hypothesis that significant differences are not to be expected in the pretest scores of the experimental and control group students.

Table III shows the results of the independent samples t-test and the Mann–Whitney U test on the posttest score averages of the experimental group and control group students.

C. Administration of the Tests

The survey test was used as both pretest and posttest, administered to both the control group and the experimental group in the classroom, before the course started, and one day after the end of the course. Students had unlimited time in which to reply. The attitude survey was similarly administered, at the same time as the knowledge test, one day after the end of the class, with students being given unlimited time to respond. Both instruments were administered in accordance with institution regulations.

D. Statistical Analysis

Data analysis was performed in SPSS for Windows software (version 11.5) using an independent samples t-test, the Mann–Whitney U test along with a paired samples t-test and the Wilcoxon signed-ranks test. The arithmetical average, standard deviation, minimum and maximum scores, range, and percentage calculations were also calculated.
Thus, the hypothesis that significant differences are expected in the posttest scores of the experimental group students has been verified. Table VI. 25% of the students showed an attitude in favor of the CAL method, are given in Table IX. According to this Table IX. 25% of the said group is at a level of 3.76–3.94, indicating that 25% of the students exhibit an attitude close to the “agree” level. No students were undecided or reported a negative attitude.

According to the results of the applied independent samples t-test, there is significant statistical difference between the posttest scores of both groups (t = −2.86, σd = 20, P < 0.01). However, since the number of samples was limited, the Mann–Whitney U test was also conducted. The results of this test also showed significant statistic difference between the groups (z = −2.57, P < 0.01). Thus, the hypothesis that significant differences are expected in the posttest scores of the experimental and control group students has been verified.

The results of the paired t-test performed upon the pretest posttest score averages of the experimental group students were found to be statistically significant (t = −15.91, σd = 15, r = 0.435, P < 0.001). These results are given in Table IV.

Along with this, since the number of the samples was small, a Wilcoxon signed-ranks test was performed and the results were statistically significant (z = −3.55, P < 0.01). These results are displayed in Table V.

According to the results of the paired t-test and the Wilcoxon signed-ranks test, a significant difference was found between pretest and posttest scores. Also, the hypothesis that significant differences are expected between the pretest and posttest scores of the experimental group students has been verified. Table VI displays the results of the paired t-test on the pretest and posttest scores of the students of the control group.

These results show a statistically significant difference between the average pretest and posttest scores achieved by the students of the control group (t = −8.27, σd = 14, r = 0.147, P < 0.001). On the other hand, since the number of samples was small, the Wilcoxon signed-ranks test was also implemented and the results were also found to be statistically significant (z = −3.31, P < 0.001). These results are displayed in Table VII.

According to the results, the hypothesis that significant differences are expected between the pretest and posttest scores of the control group students has been verified. The maximum score on the attitude survey is 85, and lowest possible score is 17. According to Table VIII, the high score given by students is 85, and low score is 64. Again, in the same table, it can be observed that mean is 72.44 and standard deviation is 5.86. The Cronbach alpha reliability of the mentioned instrument is 0.83.

The attitude scores, attitude scores averages, and percentages of the averages of the students in the experimental group, in favor of the CAL method, are given in Table IX. According to this Table VI, 25% of the students showed an attitude in the “strongly agree” level and 68.75% in the “agree” level with the CAL method. The score average of 25% of the said group is at a level of 3.76–3.94, indicating that 25% of the students exhibit an attitude close to the “agree” level. No students were undecided or reported a negative attitude. Attitudes of students towards CAL are positive.
The students in the experimental group have a positive attitude towards CAL. Of the students, 62.25% strongly agree with the CAL method, 68.75% agree, and 25% have shown an attitude very close to “agree.” No students of the experimental group registered an attitude of “undecided,” “disagree,” and “strongly disagree.” These students have a positive attitude towards this CAL.

In conclusion, this study shows that the CAL method is more effective than traditional learning method in increasing the success rate in the teaching of PMSMs and their control. Furthermore, the students in the experimental group have a positive attitude towards CAL. Increasing integration of CAL into the Electrical Machines course in the near future will expand student opportunities for self-directed learning. Further long-term research with larger samples sizes are needed in which CAL, traditional learning, and other learning methods are compared in this subject area.

APPENDIX A

Process step example for mathematical control and modeling of PMSMs.

1) Enter the following equation in Matlab format by clicking the function block of $V_q$ voltage (three minutes).

$$v_q = \frac{2}{3} \left[ v_a \cos \theta_r + v_b \cos \left( \theta_r - \frac{2\pi}{3} \right) \right] + v_c \left( \theta_r + \frac{2\pi}{3} \right).$$

Matlab format

$$\left( \frac{2}{3}\right)^2 (u(1) \cos(u(4)) + u(2) \cos(u(4) - \frac{2\pi}{3})) + u(3) \cos(u(4) + \frac{2\pi}{3})).$$

Enter and confirm by clicking the OK button.

2) Click the PI controller block and enter the values given below for achieving PI control

- **Proportional** = 0.04
- **Integral** = 21.8.

3) Enter the file section from Matlab Main menu. Then go to the desktop and from the desktop access the Fuzzy-PI simulation file by clicking.

APPENDIX B

Examples of multiple-choice test questions.

1) Which of the following equations describes the $V_q$ voltage?

a) $v_q = r_s i_d + (d(\lambda_d)/dt) - w_r \lambda_q$

b) $v_q = r_s i_d + (d(\lambda_d)/dt) - w_r \lambda_d$

c) $v_q = L_d i_d + (d(\lambda_d)/dt) - w_r \lambda_d$

d) $v_q = L_d i_d + (d(\lambda_d)/dt) - w_r \lambda_d$

IV. DISCUSSION

This research has compared the effects of the CAL method and the traditional learning method on student success in teaching of the subject of PMSMs and their control in the Special Electrical Machines course of electrical education. Results obtained show a significant difference in favor of CAL. The pretest scores of the students of the experimental group upon whom the CAL method was applied were compared with the scores of the students of the control group where the traditional learning method was implemented. As a result of the analysis performed, no significant difference was found statistically between the average pretest scores of the experimental group and the control group ($t = -0.00; z = -1.02$). Thus, it can be stated that both groups had the same initial level with respect to electrical motors and their control.

Comparison of average posttest scores showed significant statistical difference favoring the experimental group was found ($t = -2.86; z = -2.57$). Based on this, CAL can be said to be effective in increasing student success.

There is a significant statistical difference between the pretest scores and posttest scores of the experimental group ($t = -15.91; z = -3.55$). The average of the posttest scores of the experimental group shows a 36% increase in comparison with their pretest scores average. There is a significant statistical difference between the average pretest scores of the control group and their average posttest scores ($t = -8.27; z = -3.31$). The average posttest scores of the control group shows a 27% increase compared with their pretest scores average. This significant difference between the pretest and posttest score averages of both groups is only to be expected.

<table>
<thead>
<tr>
<th>Attitude Score</th>
<th>Attitude Score of the Average</th>
<th>Percentage of the Average</th>
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</thead>
<tbody>
<tr>
<td>85</td>
<td>5.00</td>
<td>6.25</td>
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<tr>
<td>80</td>
<td>4.70</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>4.64</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>4.47</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>4.47</td>
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<td>75</td>
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<td>73</td>
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</tr>
<tr>
<td>64</td>
<td>3.76</td>
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</tbody>
</table>
2) Which one or which ones of the following control effects are used by a PI controller?
   a) Proportional effect
   b) Proportional and derivative effect
   c) Proportional and integral effect
   d) Integral and derivative effect

3) Which of the following choices expresses input and output variables of FLC?
   a) $e(s), \alpha_{e}(s), \alpha_{I}(k)$
   b) $e(k), \alpha_{e}(k), \alpha_{I}(k)$
   c) $e(t), \alpha_{e}(t), \alpha_{I}(k)$
   d) $e(k), \alpha_{e}(s), \alpha_{I}(k)$

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