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Improving Learning in Undergraduate Control Engineering Courses using Context-based Learning Models*

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Control Engineering is an essential part of university electrical engineering education. Normally, a control course requires considerable mathematical as well as engineering knowledge and is consequently regarded as a difficult course by many undergraduate students. From the academic point of view, how to help the students to improve their learning of the control engineering knowledge is therefore an important task which requires careful planning and innovative teaching methods. Traditionally, the didactic teaching approach has been used to teach the students the concepts needed to solve control problems. This approach is commonly adopted in many mathematics intensive courses; however it generally lacks reflection from the students to improve their learning. This paper addresses the practice of action learning and context-based learning models in teaching university control courses. This context-based approach has been practised in teaching several control engineering courses in a university with promising results, particularly in view of student learning performances.

INTRODUCTION

EDUCATION INVOLVES teaching and learning processes. The ultimate goal is to help students to learn the knowledge. As the essential part of education, an efficient way of learning is the key factor for successful teaching. Action learning has been used in various contexts to solve problems [1]. Such contexts include industry, management and education. Based on the information obtained through action, reflection provides the advice for future actions to be modified, and therefore improves learning in future situations, as well as influences informed intentional behaviours [2]. Through reflection and group learning, action learning has been used to enhance teaching and learning in university education.

Action learning

People learn from the information obtained in feedback from both performance and self-reaction [1, 3–5]. Such a process can be an individual or a group effort. In either approach, action is used to provide the feedback. Such actions include active listening, thinking, reading, speaking or writing [6]. Reflection is the essential part to action research, which has been used to improve and change classroom practices. Action research can be described as a cycle of planning, implementation, observation and reflection [7]. The previous three steps are aimed at inspiring the students to produce information, which will be used to enable the reflection. The teachers and researchers learn from the reflection to enhance their teaching and research.

Action learning circles

Action learning is featured with its special characteristic of being circles. Action learning circles can be implemented in teaching to improve learning for students [1]. As one of the theoretical foundations for action learning, experiential learning was defined as one of the domain of knowledge as among the three domains as propositional, practical and experiential. It was defined as any learning activity, which facilitates the development of experiential knowledge [2]. The essential part of experiential learning is the ability of students to reflect on experiences, think critically and discover solutions to present problems, and inform future actions. The authors in 1 indicate that reflection is an important part in learning, but its value may be limited if it is carried out alone. As a more effective way of using reflection, action learning circles can be employed. In order to achieve effective action learning, the students need to have a positive attitude, and to have the skills to participate. The process may involve an initial sense of disorientation and confusion. However students will gradually overcome such disorientation and confusion, and move towards the effective way of learning through action circles. The authors in 1 point out that participation in an action learning circle reveals the importance of critical thinking, problem solving and decision making in the learning process. These skills were developed through sharing and reflection. Generally speaking, action

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learning offers an effective and valuable approach in education.

FROM CONCEPT-BASED LEARNING TO CONTEXT-BASED LEARNING

One of the major teaching approaches is the concept-based learning. Under such an approach, knowledge is transmitted to students as discipline-based knowledge from teachers to students. Such knowledge carries with its value for students as revealed in assessments. Concept based learning starts from the fact that teachers possess the concept, and transmit to the students by several steps. Students start from the status of no concept in the beginning; then have their concept defined, developed, quantified and finally assessed through out the learning process. During this knowledge transmission process, optional associated experiences or applications are input into student learning at the concept definition, development and quantification stages. Students are exposed with the abstract knowledge in the beginning, and have their concept defined, developed and quantified through out. In such an approach, it assumes that student maintain a willingness to learn, and that students are partially driven by the final assessment for their learning. This is predominantly teacher centred teaching, with teachers leading the students in their learning process [8]. In concept based learning, context, which is defined as 'a group of related situations, phenomena, technological applications and social issues [9],' is transmitted after the lectures. The concept-based learning process is illustrated in Fig. 1.

J. A. Comenius pointed out as early as the seventeenth century that teaching shall begin with real things, which can be felt by human senses [9]. This is the prototype of context-based learning. Context-based learning starts from a well defined real problem, with concepts or knowledge around it. Students are to explore the concept base around the problem, find the solution to the problem in a repeated way, with their concept accumulated each time they explore the concept base from the context. They finally have their knowledge develop during this repeated problem-solving and concept-searching analysis process.

The procedure of context-based learning can be summarized as the following, as shown in Fig. 2:

- Start from getting student commitment;
- set up the concept map from the context;
- framing problems and hypotheses within the context;
- (students) find out knowledge needed by investigation, research and lectures;
- finalise learning.

TEACHING ENGINEERING COURSES WITH CONTEXT-BASED LEARNING

The engineering courses at universities range from the fundamental courser to advanced special courses. Most of the courses involve a large portion of mathematical and physical knowledge. Students often find such maths-intensive courses difficult to understand. However, these courses are a fundamental requirement for a professional engineer. Students may feel obliged to do such courses in order to gain their degree in engineering. Under such circumstances, there is a general lack of interests in such courses, and therefore there exists pressure for the lecturers to try making it interesting and appealing to students away from students' career prospective as the sole driving force to make them select and study the courses.

General introduction of the course: Elec3500 Introduction to Control

The content-based learning approach had been practised in teaching of a control course 'Introduction to Control Engineering' in 2002. This is one of

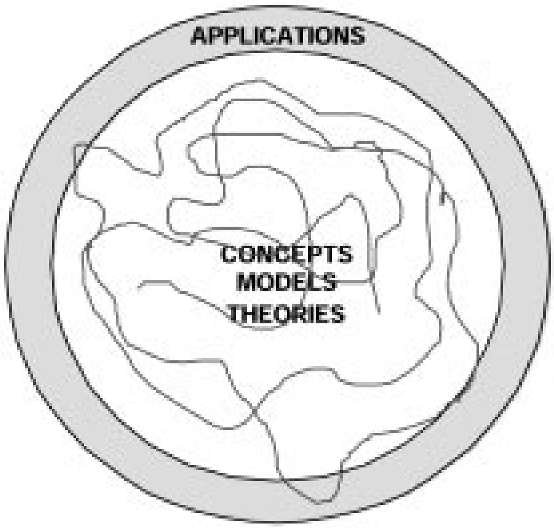

Fig. 1. Concept-based learning.

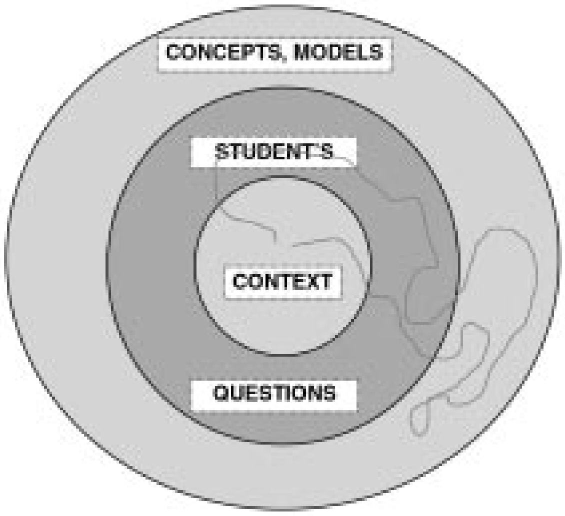

Fig. 2. Context-based learning.

the most maths-intensive courses in the engineering curriculum, and a very important course for electrical engineering education. Students who passed this course, and if interested in control engineering, can choose to study 'Advanced Control'. This course aims at teaching the students the fundamentals of control engineering as well as skills of control engineering practice to inspire their interests in general electrical engineering.

IMPLEMENTATION OF CONTEXT-BASED LEARNING

Action learning in a large class

Questionnaires were distributed to the class to collect reflection of the students' feeling of their learning perspective and difficulties, and then were used to improve teaching by addressing the common problems reflected. The questionnaires for the whole class were limited in occasions because of the student loading and the limited lecturing time. The questions were asked from general topics of the lecture/course, to detailed aspects of the course (e.g., specific topics/modules of the lecture). Selected student groups were used more often than the whole class. These students were generally more willing to participate in this action learning process. The selection of students was carried out through tutorial and lab contacts. The feedback is generally about students' feelings about the teaching effectiveness and ways to improve it. For example, some students pointed out they could not hear very clearly at the back of the lecture room, so the lecturer needed to stay close to the microphone. Some students asked to have the original PowerPoint presentations on the web instead of the pdf-format files to they can print to their own preference. Some students gave feedback on tutorial sessions and tutors' performance, which had been carefully conveyed to the tutors concerned and improved the tutorial session effectiveness.

Teaching for a large class

The lectures were prepared carefully in advance. The 3-hour lecture time were distributed as: the first 2-hour session for teaching of theorems and fundamental techniques following the course profile each week; and the second 1-hour session was used for teaching of theorems and fundamental techniques for odd weeks, and discussion and solving of large design question(s) for even weeks.

Tutorial time was mostly handled by tutors in assisting students solving tutorial questions. Every second week, the lecturer used one hour of the 2-hour tutorial time to form discussion groups in solving large design question(s).

The twp hours practical/laboratory time per week were used to solve projects like design problems using the knowledge and skill presented in lectures and tutorials. There were a total of four projects through out the semester. Student can go to the lab any time provided there were vacancies in the lab by themselves, in addition to the scheduled time slots where demonstrator help was available.

Assessment

Students were assessed by their understanding of the fundamental techniques, theorems as well as professional and systematic ways of solving real control problems.

Assessment was composed of: (i) mid-semester class test (20%); (ii) mid-semester practical test (20%); (iii) final practical exam (25%); and (iv) final examination (35%). All tests and exams were open book ones:

1. Mid-semester class test tested the students' understanding of fundamental theorems and techniques (60%) and problem solving techniques (40%).
2. Mid-semester practical test assessed students' skills and understanding of the practical projects 1 and 2. Students were required to repeat individually the first two practical projects/ modules and were assessed based on a criteria sheet specially designed to highlight the practical project soundness.
3. Final practical exam tested the remaining practical project/module 3 and 4 in the same way as the mid-semester practical test, but carried more weight because the last two projects were more difficult than the first two.
4. Final exam tested the over-all understanding of the course with 50% on fundamentals, and 50% on problem solving skills.

Other issues

Previously, similar courses are taught in a concept-based learning approach. This approach is subject to these disadvantages: (i) there is generally a lack of interest from students and (ii) the concept may be forgotten after the exams. In 2002, context-based learning was used to assist the teaching of this course. People with industry experience were invited to testify the usefulness of control in real industry in the very first lecture. A student who had been part-time working in the power industry was also taking the course, and was invited to give a short speech to give students an objective testimony. The student did an excellent job by sharing his own experience. The student also gave some audio and visual demonstration of some major control projects locally and overseas. This effectively motivated many students interest immediately. Several design problems were given in the first lecture as well. This combined presentation gave students a clear understanding of the context to be solved throughout the course. These design problems were based on motor control problems and were carried out in parallel with the lecture so that students were able to apply their concept to the real problem on time. The progressive concept contains: problem definition, variable selection, initial controller selection, theoretical design and stability proof, control implementation, software selection, hardware design, overall design and testing, and the finalisation stage report followed by the practical exam.

The procedure of context-based learning for teaching of Introduction to Control Engineering can be summarised as firstly to start the teaching at getting students' commitment and interest. Then a concept map from the context was set up. This was then followed by framing problems and hypotheses within the context. Accordingly, students were required to find out knowledge needed by investigation, research and lectures before finalising their learning.

CONTENT-BASED LEARNING CASE STUDY

The content-based learning techniques had been applied in teaching of Introduction to Control Engineering course. Probably the most important factor in content-based learning is the careful problem design. One of the problems designed is a servo motor system, which had been used through out the teaching. The system forms the basis for antenna azimuth position control system case study. The servo motor can be controlled by input voltages. The output of the motor is measured by the angular position of the flywheel connected with the motor rotor. The servo has a fixed field DC motor that drives a high reduction gearbox. The gearbox is highly damped (it has high friction). The output of the gearbox is connected to the flywheel load that has considerable inertia. The output shaft is directly to a potentiometer for feedback. The students were required to build two different types of controllers:

1. An analog controller that will consist of a differential pre-amplifier and power amplifier derived from op-amps.
2. A digital controller consisting of a PC, data acquisition card and a power amplifier derived from an op-amp. MATLAB and Simulink will be used, in particular, the Realtime Windows Target library to design and simulate the controller in real time.

The operational amplifier used was a L272 dual op-amp. The package has good supply range characteristics, good gain-bandwidth and a hefty 1 A output power rating. This is normally sufficient to drive the motors in most circumstances, although power dissipation limits must still be observed. Students were required to find the open loop time response of the motor system. This can be achieved by applying a step voltage to the motor and recording the voltage seen at the potentiometer. Based on this time response the transfer function of the motor system can be derived.

The servo has a motor, a gearbox and a load. The potentiometer is connected to the load, with the potentiometer powered from a separate voltage supply. The input of the system is the applied voltage to the motor. The output can be viewed in two ways: the angle of the flywheel, or the voltage on the potentiometer. Although typically the angle of the flywheel is regarded as the output of the system for its application (e.g. antenna azimuth position) in this case the potentiometer voltage is used as an output.

The system will be predominantly a first-order system. In this case the constants associated with the individual parts of the system are unknown. These constants include motor constants, inertia of the load or even the gear ratio. This means that we will have to treat the system as a black box from which we expect a first-order response. Given that a first-order response is expected, one can write the transfer function for applied motor voltage to potentiometer voltage. There is no need to derive values or expressions for the system parameters. Rather than system parameters will be measured for subsequent experiments. The transfer function has the form:

$$\frac{V_p(s)}{V_m(s)} = \frac{K}{s(s+\alpha)} \tag{1}$$

which means that the whole servo system can be characterised by two numbers: K and α.

This servo system is used for understanding system modelling, system block diagrams, signal flow diagrams, frequency response, and controller design with various methods thoughout the course. This model is described in the beginning of the course, so students have a better understanding of one of the contents on which their study of control engineering should be focused in the semester. Specifically, the learning of introduction to control engineering includes system modelling, open loop response, closed loop response and compensator design. These major components are described in the sequel for completeness.

System modelling and open loop response

In this experiment, students are to find the open loop time response of the motor system. This is achieved by applying a step voltage to the motor and recording the voltage seen at the potentiometer. Based on this time response students should be able to derive the transfer function of the motor system.

Step response is realised by connecting the motor system to the analog-to-digital converter on the data acquisition card inside the PC. This AD converter can then pass data through Simulink into MATLAB variables for analysis. Simulink can also control the digital-to-analog converter on the same card to produce input signals. The signals are passed to and from the PC using a breakout box, the National Instruments BNC-2110. The system model will take the form as shown in Equation (1). These two parameters k and a derived through this experiment forms the basis of almost all subsequent experiments. Students are required to perform this experiment properly, and record data carefully. Students are also recommended to repeat the analysis on several sets of data, and always be careful to minimise the effects of nonlinear elements such as backlash in order to obtain better value of the parameters.

Closed loop response

The open-loop response of the system found from previous experiments is of little value from a position control point of view. Based on the model produced it is necessary to switch the motor on and off at precise times to achieve open loop position control. Furthermore, any disturbance to the system (such as a change in load or damping) would destroy the calibration required for open loop control.

Feedback or closed loop control will relieve these problems, but introduces a new level of complexity to the system. To achieve feedback control, students must difference the desired position of the motor from the measured position and use this result (the error) to drive the system. The purpose of this experiment is to implement a proportional gain feedback control loop around the motor. For this task students are going to use the amplifier circuit from Experiment 1 to power the motor and to implement the feedback system using the real-time workbench of MATLAB/Simulink.

An important issue is saturation of voltage that students must address from this experiment. While all components are capable of delivering the current required (within thermal limits), the voltage is strictly limited by the rail-to-rail supply of the operational amplifiers. To prevent overdriving the motor, it is required to run the system from +6 V to ±6 V, as the largest voltage can be applied across the armature terminals is ±6 V.

Students will investigate the performance of proportional gain feedback control in this experiment. Proportional control is the simplest form of feedback control. The idea is to difference the desired position from that measured by the potentiometer to produce an error. This error is then multiplied by a constant (or gain) and the result is outputted as a voltage. This voltage is amplified by the op-amp circuit and applied to the armature of the motor. The control loop is shown in Fig. 3, where K_p is the feedback gain.

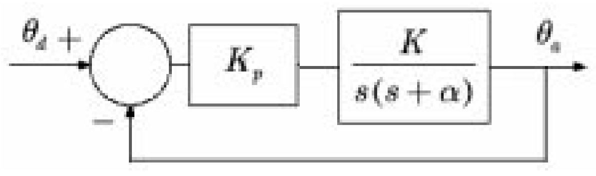

Fig. 3. Block diagram of the closed loop system.

Students are required to build a *Simulink* model of the closed-loop system based on the system model they have developed and simulate the response of the system to a unit step change in commanded position. Students are also required to find out the impact of varying the feedback gain K_p on the closed loop system response and determine a feedback gain which gives a specific overshoot, e.g. 5%.

Compensator design

Based on the previous experiment results, students will learn how to apply root-locus design methods to select a cascade compensator $C(s)$ in the feedback loop shown in Fig. 4 to meet a design specification involving transient and steady-state response such as:

- the steady-state error is zero for step inputs and less than1% for ramp inputs;
- the overshoot of the system is less than 10% to step inputs; and
- the settling time is less than 0.15 s.

Students are required to design a lead or lag control covered in the lectures—see Equation (2).

$$C(s) = \frac{K_1(\alpha s + 1)}{\beta s + 1} \tag{2}$$

Students are to determine suitable values for K_1, α and β so that the compensator meets the design specification. Students are also required to explore other forms of compensators as given in the following to enhance their learning:

Proportional plus integral (PI)

$$C(s) = K + \frac{1}{k_i s}$$

Proportional plus derivative (PD)

$$C(s) = K(1 + k_p s)$$

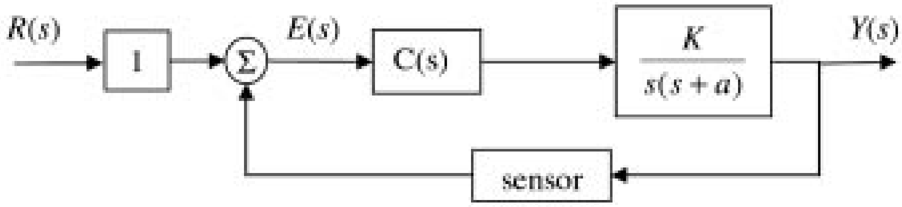

Fig. 4. Block diagram of the system with a compensator block.

Table 1. Student performance through assessment.

	Mid-semester test	Mid-semester practical exam	Final practical exam	Final examination
Performance	High	Low	High	Medium High
Comments	Questions are set to test closely related to the context.	Students need more linkage from Context to Concept; Plus lack of revision time.	More practical sessions, and more understanding from contexts	Students' over all comprehension of the course has be improved through context based learning; Plus more revision time

Proportional plus integral plus derivative (PID)

$$C(s) = K(1 + \frac{1}{k_i s} + k_p s)$$

It is observed that many students do explored the three compensators (PI, PD and PID) following successful implementation of the lead-lag compensator. Through this experiment, the root locus method in compensator design is strongly enhanced.

The laboratory practices, tutorial problems and lectures help the student gain a better understanding of control engineering holistically. Students know what exactly they need to explore in control engineering knowledge base after lectures with the servo motor problem in mind. The knowledge they obtain via different sources will in turn enhance their learning of the control engineering knowledge. This content-based approach had been proven as effective through the outcomes of student learning. A comparison of learning effectiveness is given in Table 1.

CONCLUSION

Engineering courses involve large amounts of scientific and engineering knowledge which are traditionally believed to be difficult to understand without abstract thinking effort. Such characteristics often made engineering courses not very interesting/attractive for average students. Some students study such courses merely to get their degrees, and are mainly driven by assessment/exams. It is a task of teaching engineering courses with student interests and some initiative. Most university undergraduate students have no real working experience, and therefore do not realise the fact that many of the fundamental courses they are studying at university will be essential in their later engineering or management career. Under such situations, effort should be made to inspire student interest and to help them understand the importance of the course in an effective way. Context-based learning turns out to be one of the right choices of effective teaching and learning approaches. It can inspire student interest to explore and learn the knowledge around the context. The context-based learning approach has been applied in teaching of Introduction to Control, in an adaptive way to reflect the characteristics and needs of engineering course.

The practice of teaching engineering courses has traditionally been nearly 100% concept-based teaching. The practice of action learning and content-based learning approach for teaching control courses had changed the engineering and mathematic courses from scientific and numeric world into something more attractive, more appealing to the majority of students. It indicated a contradictory view to the common belief that engineering courses are mathematics-based, and there is very limited attempt to make the teaching of these courses interesting unless the students understand the real value of the courses.

The new way of teaching greatly inspired students' initiative of learning through reflection from people with real engineering experience and their belief in the usefulness of the courses, as well as the context of linking the scientific concepts with engineering practical design problems. In this way, the previous 'boring' course has now become interesting and appealing for students. As a result, the course attracted many more students than before. Despite the shortage of sufficient laboratory facilities to accommodate the sudden increase in student enrolment, most students perform well. This course motivated students' interests into its subsequent advanced course—Advanced Control. The feedback from students also reflected such impact from action learning and context-based learning practice throughout the course. Some students wrote to the lecture saying that this course was the best engineering course offered from the school. Some other students nominated the lecture as the most effective teacher in the faculty because of this context-based learning approach in the course.

The outcomes of such practice are remarkable. The course attracted large number of students in engineering discipline. Students showed interests in the context of designing a controller using their concept transmitted in lectures and other resources. Many students reflected that they become very interested in control engineering after taking the course, through lectures and lab sessions. Subsequent large numbers of enrolment into the advanced control course (68 against 20 previously) most effectively reflected the effectiveness of this teaching approach and its impact on students. Context-based learning has really made the teaching of control very effective and attractive to students.

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