Understanding Best Practices in Control Engineering Education Using the Concept of TPACK

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Abstract – **This study aimed to design an integrated pedagogical approach to advance introductory Process Control Engineering Education through the application of the Technological Pedagogical Content Knowledge (TPACK) framework, and evaluating its impact on student learning. The research is initially being undertaken at Nottingham Trent University, UK but we will next adapt it to a case study in Libya. This paper aims to strengthen the teaching of introductory Process Control by using appropriate approaches in universities to improve the learning outcomes for students. From this work a new schematic for teaching Process Control has been developed and, moreover, a thoughtful best practice in introducing Process Control in engineering education can be developed.**

Index Terms - TPACK, Engineering Education, Process Control.

INTRODUCTION

This paper presents research on the application of Technological Pedagogical Content Knowledge (TPACK) for the teaching of Process Control in engineering and the incorporation of the research results into suitable technological content and pedagogical approaches, within an integrated modern teaching framework. This includes a pilot study undertaken in an MSc module at Nottingham Trent University, UK (NTU). For the last 4 years this module has been part of a collaborative link with institutions in Libya which involved students coming to the UK and studying this module. These students had a background in control theory but with little exposure to modern IT tools use in control and no previous training in Process Control. An alternative to University education in Libya is for organizations to bring in outside consultants at great expense to deliver specialized courses on isolated networks. The research here is aiming to formulate a pedagogical framework for the UK based Process Control teaching, delivered in part to Libyan MSc students on a collaborative program, and transfer it to the Libyan MSc level educational and equivalent specialized industrial training systems.

Currently, teaching Process Control to engineers relatively new to the subject, is an important part of improving their engineering knowledge, as automatic control and monitoring have become increasingly important in many major subject areas. The MSc teaching at NTU in the Process Control area has always been mainly project based with a heavy reliance on IT tools such as MATLAB, Simulink and Agilent VEE [1]. MSc major projects have also been have been carried out in the Process Control area, sometimes with the inclusion pedagogical aspects. However, until the start of the current research no formal overall pedagogical framework has been produced to integrate the teaching approach to these areas.

The requirement for control and signal processing systems affects various areas in the lives of human beings for example technology, medicine, economics, and more importantly its role in the industrial and productivity applications. For the last thirty years, the evolution in automatic control systems contributed to the efficiency and success within the industry. There are educational challenges faced teaching Process Control everywhere [2].

The TPACK framework refers to a technology integration model that aims to integrate teaching processes with teaching competencies. This framework model focuses on the knowledge of teachers in technology as well as the integration of technology, content and pedagogy. The need for a more comprehensive and rational theoretical framework was recognized about the content knowledge of teachers and how this knowledge can be translated into effective teaching practices [3]-[4]. A better understanding of the pedagogical and technological approaches is needed to achieve the target of implementing the approaches developed (in this study). The future stage, following this work is to utilize this new approach to understand the best practice in Process Control education, using the concept of TPACK, as a case study in Libya.

LITERATURE REVIEW

Pedagogical principles are a growing science [5]. One modern pedagogical approach, TPACK, is a “framework to understand and describe the kinds of knowledge needed by a teacher for effective pedagogical practice in a technology enhanced learning environment” [6]-[4]. The TPACK framework model essentially consists of seven domains (1) Content Knowledge (CK), (2) Pedagogical Knowledge (PK), (3) Technology Knowledge (TK), (4) Pedagogical Content Knowledge (PCK), (5) Technological Content Knowledge (TCK), (6) Technological Pedagogical

Knowledge (TPK), and (7) Technological Pedagogical Content Knowledge (TPACK). Of these seven domains, CK, PK and TK are the core domains whilst the other four are complementary domains. The three core domains are described below.

Content Knowledge can be referred to as the ideas, principles and theoretical frameworks that govern the development of knowledge [7].

Pedagogical Knowledge is the standard or basic knowledge associated with teaching methodologies, student learning, assessment strategies and knowledge of various theories of learning. The pedagogical knowledge, although essential, however does not suffice the needs of teaching practices alone. It is complimented by the content knowledge.

Technology Knowledge generally refers, in school or university learning, to the basic knowledge about the digital technologies; for instance the internet, computers, laptops and associated software applications. The knowledge about technology also aims to improve the objective of the existing technologies to be used in technology heightened environments [8].

The process of formation of Technological Pedagogical Content Knowledge, through bringing technology into content and pedagogy, is highly complex and challenging, involving a multistep developmental procedure [8].

RESEARCH DESCRIPTION

The research conducted in this study, makes use of the TPACK framework to teach Process Control at NTU as a case study to develop better practices in using suitable pedagogy and technology for engineering control education. The novel approach, developed during the research, offers an improved approach to teach Process Control which allows for more discussion of principles and practices. Many researchers, in the engineering education research field, concentrate on understanding how to prepare engineering students for industrial needs [9].

The importance of guiding lecturers is to use both the appropriate approaches to deliver the knowledge and to convoy the rapid developments in this field, in order to improve learning outcomes of engineering education. In teaching and training, in current industrial engineering education, various education strategies or perspectives have been taken towards enhancing the learning outcomes and to provide trainees a better education; such as using technology, E-learning and learning based project, etc. [10].

DISCUSSION OF THE PERSPECTIVES

Here we will present two different perspectives. The first of which strongly supports the use of modern technology and computers in education and considers it as very important [11]. The second view is that using technology in education is useful but not for all educational outcomes [8].

The use of modern technology and computers in education presents a significant issue. More recently a meta-analysis of over one thousand studies, by the US Department of Education reported: "In many of the studies showing an advantage for online learning, the online and classroom condition differed in terms of time spent, curriculum and pedagogy. It was the combination of elements in the treatment condition that produced the observed learning advantage." [12]. According to the report of DCSF (2010), the use ICT in school learning can help improve the standards by improving the quality of teaching, management and learning. Much attention has been given recently to modern education and E-learning [13].

There are justifications supporting the second view about the technology usage in education. Dormido [10] gave a leading idea to all educators: "Educators must have an open attitude towards new technologies. They should sensibly incorporate new technological development to avoid the risk of teaching the students of today, how to solve the problems of tomorrow, with the tools from yesterday." E-learning uses different variables and it can be difficult to predict the outcomes of these variables depending on different situations in which E-learning is used to deliver learning skills. In different situations, it is difficult to establish which aspect of the technology mediated learning is useful.

RESEARCH DESIGN

The following schematic has been designed to build the perspective for the sustainable teaching of Process Control engineering.

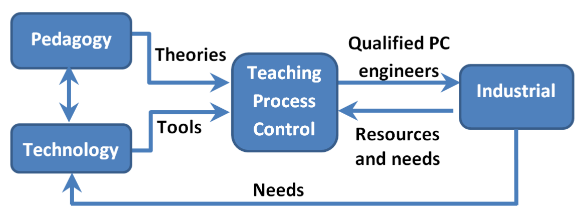

FIGURE 1
SCHEMATIC OF USING TPACK TO TEACH CONTROL ENGNIEERING

The teaching of Process Control designed in this research study is presented schematically as shown in figure 1. Teaching Process Control is affected by three main factors; industry, technology and pedagogy, all of which are interlinked. Industries provide much of the resources needed for teaching Process Control. In turn the teaching of Process Control provides industry with necessary skills. Pedagogy provides the theoretical knowledge essential for the best methodology for teaching these skills. This includes different teaching methods, the design of different assessment methods and the theories behind different learning skills. Technology provides some essential tools required for teaching Process Control, such as computers hardware and, various useful forms of software, packages and programs. The combination of these three factors makes the teaching of Process Control much efficient to execute.

From the main domains of the TPACK framework (content, pedagogy and technology) we will start to simplify the practices that we need to reach the best understanding of using the framework. In addition we highlight the borders between theses domains and conjoint areas.

Firstly, let's start with the content: the content should be compatible with the industrial needs to provide qualified engineers for the labor market. Astron [14] discussed in his presentation on the perspective for Process Control engineering, illustrated in figure 2 below, that there are borders between these subjects: between control and mathematics, computer science, physics, etc. For example; we need the control student to understand the physical meaning of control components and how they can be mathematically modelled before they are converted to a control program, and then compiled and implemented in control hardware. The barrier between control engineering and computer science can cause problems when they need to work together on an industrial control application, if the control engineer does not know enough about the related computer science, or the computer scientist does not know enough about the related control engineering.

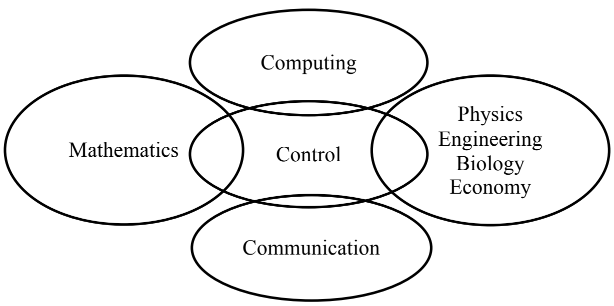

FIGURE 2
THE SYSTEM PERSPECTIVE OF CONTROL CONTENT

As shown in figure 2, there is a common area between Process Control and computer science, both of which are young and rapidly developing subject areas. Astron stated that we started teaching control and delivered the first course, then we learned a bit more, then we made a new more narrow course, then we learned more then made a new even narrower course…. and so on [14]. The courses become more and more specialist and this issue causes educational challenges as the specialist students need awareness of the subjects they interact with. We will discuss content issues and how they affect Pedagogical Knowledge (PK) to meet these challenges.

Secondly, we will consider pedagogy: successful teaching and training of Process Control programming and hardware interfacing is challenging for several reasons. For example the new versions of microcontrollers have complex systems, with handbooks of more than a thousand pages. It takes a long time to become familiar with a microcontroller family in the detail necessary for course integration; a time-consuming task for a teacher or trainer [7]. Here we see the conjoint area between content and pedagogy to get the fourth domain Pedagogical and Content Knowledge (PCK). This domain defines the combining of knowledge (content and pedagogy) to show how we can make a subject understandable [15]. As discussed above, the subject of Process Control is new, rapidly changing and expanding; therefore there is a need to continuously change the curriculum to meet the current industrial requirements. The result of this educational challenge occur (How to teach the future engineers). Discussing this challenge and to help modify the contents of the curriculum, by receiving feedback from the industrial sector also costs time and effort. Furthermore many of these updates could easily be obtained from the research department in the universities, which are considered as a 'theater' to develop practical industrial research, as we built our approach in Figure 1.

Thirdly, we consider technology: computer technologies offer the ability to visualize and manipulate control objects in an interactive way; this is really useful in education, to simplify conception of the ideas delivered to the students and to separate these from the complexity of the control mathematics [16]. E-Learning has become an increasingly important approach for all subjects. In its comprehensive definition, E-Learning includes transmitted lessons via all electronic media. For example CD-ROM, internal or external memory, servers on Internet or intranets, interactive TV, satellite broadcasts, and media elements, as words/pictures/audio/video, to deliver the content [5]-[17]. Here we will highlight the fifth domain where content is shared with technology in the area of Technological and Content Knowledge (TCK). This domain describe the ways of using technology for better teaching. Such as animation, or video or etc. to make it easier to imagine the theoretical or physical phenomena under examination [18]. Although it is very useful to use technology to explain and simplify the content, however sometimes it is better avoiding the use of technology. This depended on which skill we want the students to learn, for example, using Bloom's Taxonomy to decide the best teaching approach [19]. If we are expecting the students to reach the level of 'apply' not only just 'know', we need to support them by doing exercises.

The sixth domain is the common area between Pedagogy and Technology, (TPK), that is if we need to assess by technology (for example an online 'test').

To build online learning material, interactive assessment and other interactive lessons authoring tools could be used. There are many author tools [20] such as, Adobe E-Learning Suite, eFront, elab, App Inventor – (mLearning), CamStudio, LAMS, eXe, ClassTools.net, ProProfs, Automation Anywhere, mindflash ,etc. In addition, there is an ability to link work in packages such as MATLAB and AGILENT VEE direct, without author tools.

E-learning is a fairly new development but can lack pedagogical principles [21]. Extending the application of pedagogical principles in E-learning is needed to design effective tools that follow rapid changes in technology [5].
Ragusa and Lee in their study stated that "there is an urgent need for comprehensive educational research reform efforts that are tied to career-focused student performance and impact assessment." [22]. Furthermore, Zaharias and

Poylymenakou mention that: “current improvements in engineering education have occurred as original attempts to meet the changing needs of engineers worldwide” [23]. Several institutions of higher education and training centers are using E-Learning to help solve weakness of learning and performance, but some institutions are using it without enough care about fundamental requirements for effective implementation of E-Learning. Govindasamy said in "Successful implementation of E-learning: pedagogical considerations” that: “one of the most crucial prerequisites for successful implementation of E-Learning is the need for careful consideration of the underlying pedagogy” [5]. This area is still not always covered well and there is certainly a need for more research [24].

The seventh domain is TPACK that describes the relationship amongst the main domains Content Knowledge, Pedagogical Knowledge and Technological Knowledge while technology is applied in progressing teaching or learning. In addition it covers the difficulty of the relationship between the student and tutor. Project-based learning is one of the key teaching and learning methods in a practical subject [25] like Process Control to apply this method we need to understand the seventh domain for successful application. After explaining the definition, the border areas and the challenges, now we will briefly present our case study.

CASE STUDY

Building on the previous work in this area in the MSc Digital Control module and MSc major project work on Process Control, we set up a case study in the Digital Control module. We examined the TPACK framework in the module where Process Control is introduced to engineering students, often for the first time (although they do have prior control theory knowledge). It is important in this module that students understand the key principles that will enable them to work alongside Process Control experts and use the equipment they work with safely and successfully. On the education (pedagogical) approaches, we improved the methods of presenting course material in lectures, for instance by adding improved aims and learning outcomes. Regarding the process of lesson planning we followed scientific steps. After choosing the lesson topic, the following main three steps were specified; Objectives, methods and evaluation, and in each step we investigated the steps, as below [26].

- What we want the student to learn from this lesson.
  - Select the learning outcomes.
  - Select and organise content.
- How we are going to access that learning.
  - Select appropriate teaching and learning strategies.
  - Select and develop teaching and learning resources.
- List out our assessment objectives for the assignment (connect it to real industrial applications).
  - Incorporate appropriate assessment procedures.
  - Implement learning evaluation and respond to the subsequent feedback.

Content Knowledge was applied in the first step (Objectives), as informed by the resources needs of industry.

We applied the concept of PCK in the second step (methods) of the lesson plan process, to determine which strategies were employed in teaching to offer the best learning experience for all students. In addition to the TCK and TPK, we determined which teaching techniques are needed to explain the content and which technologies can be used to enable the best teaching approaches. In particular in this module we were looking at introducing IT based tools using project based learning.

Pedagogical Knowledge was applied in the third step (evaluation), at the same time we applied TPK, as we use technology in assessment.

Technological Knowledge was applied in the second and third step (method and evaluation). How the content was to be delivered, for instance by using Power Point slides, or video or IT package introductory demonstrations. Moreover, which software should be used to simulate and implement Process Control, from theory to practical design outputs.

ANALYSIS AND RESULTS

To evaluate our approach, we used interview research to obtain feedback on the appropriateness of the three main steps of: objectives, methods and evaluation. Aspects of pedagogical and technological and content knowledge were all assessed.

The students expressed that in the main areas of objectives methods and evaluation, the framework was successful, enjoyable and useful. And the practical approach was supportive by refreshing the previous theoretical knowledge needed to build new knowledge. Regarding the theoretical and practical, we tried to support this by the real life examples. However one student’s feedback was, to improve clarity, it might be better to provide more explanation on the all the systems used as examples rather than just the one that was used in the laboratory learning exercise; this could be easily be included in the module in future as additional information (not directly related to the practical work). They liked the mixed presentation of lectures/seminars/labs including PowerPoint, video clips and written illustrations on a whiteboard and practical examples on the IT tools. One of student said if we utilized more interaction in the lecture delivery within the practical examples on Agilent Vee Process Control software, by using video clips for example, this will hopefully reduce reliance on less than ideal program help files. Regarding the use of suitable technologies in Process Control engineering teaching, we are using MATLAB, Simulink and Agilent VEE as very powerful software tools in Process Control to simulate theory and design, to assist the development of practical control solutions. We incorporated some video material to improve the explanation of PID controllers by using Simulink and the PID tuning tool. A key benefit of using video as a saved resource provide an students an opportunity to review and re-watch at any time, and they found as part of the total learning process this was useful and convenient to apply to the exercises. They also found the video material clear and interesting.

As an example of the approach we used, in one MATLAB laboratory exercise we first aimed to learn how MATLAB script can be produced to calculate some parameters. By this exercise we allowed them to practice reaching the skill of applying knowledge, as in Bloom's taxonomy categories [19]. In the second stage they utilized an existing section of script which they needed to understand and adapt. From the first stage, the students were able to understand the difficulties in producing code for themselves (especially learning from mistakes) before they utilized code from others in the second stage. As a result, from the analysis of the interview feedback, most of the students considered that applying this type of approach is helpful and effective. There are some areas of feedback where we can improve. Plus there may be new aspects of improvement required when we are ready to test it in Libya.

FURTHER RESEARCH

Further research is intended into how we can apply this framework for the improved teaching of Process Control in developing countries. The case study for the next stage of the research is Libya, where many factories, oil fields and other service agencies, such as airports or ports, need qualified control engineers to solve their problems. To train them, suitable equipment and facilities are needed. All of these currently have high costs, because they often need high level of expertise and expensive training of hardware and software, mainly imported from overseas [27].

There are more difficulties faced by the education systems in subjects of automatic control, engineering and applied sciences in some developing countries as consulting overseas consultants can cost huge money. Dealing with this problem and the constant changing requirements of the workforce pose a huge challenge. To deal with this problem the technology, education and training centers have to react as efficiently as possible to the ever evolving skill requirements in the industry. This is especially important for developing countries in order to fill the skill gap with the industrialized world [28].

The experience of delivery on collaborative programs at NTU hold much hope for such research to be transferred to Libya as the Libyan MSc students enjoyed the Process Control elements of the module which were new to them, as was the use of modern IT based design in this area. Obviously the IT infrastructure and skill set of academics in Libya need to improve but it should be possible to pilot delivery in the near future at a small scale, with the added benefit of a TPACK framework. As mentioned earlier, organizations (oil companies, etc.) already deliver specialized courses on isolated networks but this leaves little behind in the development of the improvement of in-country training facility and staffing.

The political and economic circumstances in Libya not only disturbed the country's whole infrastructure but also gravely affected the higher education, which led to grave challenges being faced by the engineering education, some of these are listed below [29]-[30]-[31]:

- Reliance on traditional approaches of learning.
- Absence of technology in learning and teaching.
- Deficiency of the material assets essential to execute the learning programs initiated by higher educational institutions.
- Lack of effective strategic planning in higher educational institutions.
- Deficiency of training programs for some teaching staff essential for their development.
- Lack of expertise in the academic staff to effectively use modern technologies in teaching.
- Lesser collaboration and coordination between training centres and higher educational institutes.

Dynamic Process Control in automated installations is quite complicated, which requires the staff to be appropriately trained in governing, monitoring, detecting and rectifying the faults. Therefore there is an increasing need to train learners, especially in early stages, for task management [32]. The ultimate idea behind this study is how can we establish developing education with the available facilities. We will test the impact of applying TPACK framework with our new approach in Libya as a case study, and the results might be adapted in other developing countries to move towards self-sufficiency and support their economy.

SUMMARY

To summarize, we are translating research from our study of using TPACK framework into improved Process Control courses for non-specialist engineers, who will then be better able to communicate with specialists in the real world of industrial applications in this area. In addition we described the best understanding for integrating technology and pedagogy for evolving introductory Process Control Engineering Education. We propose supporting the understanding of the purpose of learning to choose suitable pedagogical and technological skills for a better learner experience. We have also designed a novel scheme linked to the TPACK framework which we hope to link to the industrial needs of engineers who need to communicate with Process Control experts and safely and efficiently utilize the systems that they produce. We plan to test this schematic to accelerate the uptake of quality Process Control education specifically in the Libyan environment, as an example of a developing country with issues in this area.

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