Active Learning Approach in Developing Engineering Design Skill through Open Ended System Specification

John P.T. Mo
RMIT University Melbourne, Australia
John.Mo@rmit.edu.au

Peter Dawson
SAGE Didactic, Adelaide, Australia
Peter.Dawson@sagedidactic.com

Muhamad Arfauz A. Rahman
RMIT University, Melbourne, Australia
muhamadarfauz.arahman@rmit.edu.au

***Abstract**: A collaborative partnership between RMIT University and SAGE Didactic established an automation education facility supporting multi-level learning requirements. A new concept of open ended active learning is developed on this facility to stimulate creative thinking in automation problem solving. Automation systems development is a very meticulous process that depends on the way systems are specified and combined with the experience of the systems designer. The change in course design philosophy provides a significantly different learning environment within the collaborative facility encouraging creative ideas to be tested and confirmed.*

Introduction

The rate of change of sophistication and breadth of technologies used in industry is increasing at a phenomenal rate. As Australia's leading privately owned integrator of automation systems, SAGE has the industrial needs to utilise and develop latest technologies. In order to focus its core activities of building integrated solutions for Australian manufacturing industry, SAGE established SAGE Didactic, which aims to deliver practical knowledge of integrating automation systems technologies to staff and clients through its specially developed training facility located in Adelaide, South Australia. In 2008, RMIT University and SAGE Didactic entered into a formal agreement to collaborate the effort of "Advancing the technical skills of today's and tomorrow's workforce". The core of this agreement is the development of RMIT-SAGE Automation Training Centre (ATC), which is located in the School of Aerospace, Mechanical and Manufacturing Engineering of RMIT. SAGE Didactic will maintain and update the SAGE equipment in the ATC for the life of the agreement (Mo et al, 2008)

By partnering with RMIT to develop the ATC, SAGE can improve the transfer of automation system design skills to the industry community in Victoria and beyond. Automation systems design is an engineering design activity and as such relies on the engineer's intuitive ability in systems concept as well as his/her knowledge to make use of available resources. The professionalism demanded on new engineering projects forced educators to re-think the way engineering education should be transformed (Barbieri & Fitzgibbon, 2008). This is a challenge for universities because, traditionally, creativity is difficult to teach in a classroom environment (Claxton and Edwards, 2006). This paper describes the development of a new set of design learning activities in reconfigurable systems that aims to invoke creative thinking in a manufacturing degree program. Like many industry projects, there is no one single solution for the specified system outcomes of an automated manufacturing system. The students have to actively search and decide system parameters or a combination of available components that can be integrated to produce the desired results. This new set of learning activities is made possible by adapting an open-ended system specification within the learning environment of the ATC.

Systems Design Challenge

One of the primary education objectives of the ATC is to produce "work ready" manufacturing engineers. For manufacturing engineers, an essential capability is to design new automation systems for cost effective manufacturing. Automation has applications at all levels of manufacturing in the industry. Gowan and Mathieu (1996) described a commonly used five level manufacturing factory model that engineers need to manage in a typical manufacturing environment (Figure 1). In a factory, it is the task of the manufacturing engineer to design the manufacturing systems with seamless interfaces between components and levels. Using this model, education program developer can identify the systems design skills requirements of manufacturing engineering graduates.

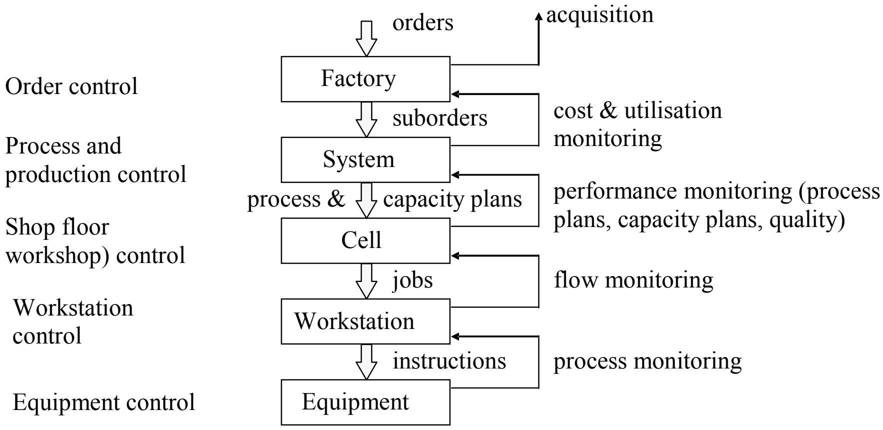

Figure 1: Five Level Factory Model

In recent years, a key concept to remain competitive is the utilization of reconfigurable manufacturing systems that is quickly adaptable to a wide variety of manufacturing requirements (ElMaraghy, 2006). Similarly, Klampfl et al (2006) showed that changes in customer demand could be met by mixed-model assembly lines that enabled manufacturers to build different products using the same equipment and facility. These researches show the importance for manufacturers to have manufacturing engineers with the ability of designing and developing new manufacturing systems from a wide variety of configuration possibilities. Hence, it is necessary that undergraduate students should be trained as thinkers and innovators. The educational goal is to encourage creativity by designing and experimenting with different ideas towards a given problem. The solution thus provided may not necessarily a complete working solution but it should reflect in a generic fashion how the industry operates.

Automation systems at equipment and workstation levels use mechatronics components extensively. Design of automation systems requires intuitive and yet systematic approaches (Mathur, 2007). The equipment level system design requires students to attend to the details that will realise the implementation, i.e. to make it work. Workstation level problems are best for practising system integration skills. The issue is that these concepts have been taught in classrooms traditionally but the students are unable to have good grasp of the concepts until they see the systems after graduation.

Dutson et al (1997) surveyed over 100 papers on the practices of teaching engineering design through project-oriented courses. They concluded that although the individual structures of the courses were diverse, the objective was basically the same, viz, providing students with real-life engineering design experience. Malmqvist et al (2005) studied the effectiveness of the application of CDIO concept in engineering education. They found that the most important benefit was to provide a basis for systematic program development. One of the effective approaches for engineering design course development is studio learning style, which involves confronting learners with situations modelled on professional practice (Armarego & Fowler, 2005). The instructor acts as facilitator, rather than information provider, to guide the students in a rich, holistic learning environment. This theory is elaborated further as work-integrated learning that focuses on task learning and domain related support (Ulbrech et al, 2006).

A good system is designed with high reconfigurability, which relies on the use of reusable components that have well defined interfaces for integration. Hence, the system design activities in the course are developed with the idea of “build from components”. By having the flexibility of adding new engineering models into the simulated environment, innovative ideas for new products and equipment can be explored. The ATC supports learning of systems design skills at both the equipment and workstation levels, and to a lesser extent, experimenting integrating issues at cell level. The ATC is the ideal environment to implement this strategy.

The Collaboration Arrangement

The ATC provides an opportunity for RMIT and SAGE to develop work-integrated-learning (WIL) curricula that incorporate the integration of control theory with real work practices, work based projects and placements. To achieve this goal, RMIT will need to develop an integrated learning package that builds on automation system design concepts. The B.Eng. (Advanced Manufacturing and Mechatronics) program has been launched as a modified program replacing a previous management oriented program. This program change represents a significant increase of content in mechatronics and automation. One of the courses going through this change is “Work Systems Design”, which aims to develop the students’ ability to design large scale, multi-activity automation systems for sustainable manufacturing, infrastructure and occupational, health and safety control requirements.

The ATC is equipped with the Targeted Training Introduction Module (TTIM™) system, which won the President’s Award in Engineers Australia’s Australian Engineering Excellence Award 2008 (http://www.vervecreativeaustralia.com/EA/video/video.php?id=b2808ffe4f1c1789380). The TTIM™ system imitates a set of industrial automation equipment with a highly reconfigurable system. The flexibility allows the students to design infinite number of experiments using the limited number of resources. The essence for this to succeed is on how the solutions are presented to the students.

TTIM™ has several versions. The most commonly used version is the conveyor TTIM™ that has a variable speed conveyor and a large number of pneumatic cylinders and sensors as accessories attached to the conveyor. This version can be used on a work bench supporting 2 to 4 students working in a team. Different system outcomes can be achieved by different combination of components and mechanisms over the conveyor. Figure 2 shows a completed form of a conveyor TTIM™.

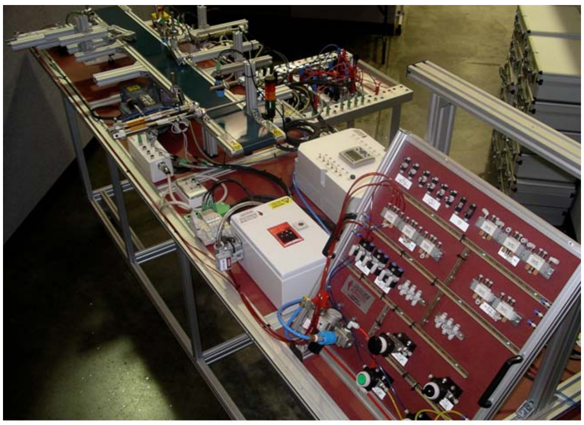

Figure 2: SAGE Didactic training platform

Apart from training and undergraduate programs, the RMIT-SAGE ATC will also foster collaborative research between RMIT and SAGE, and potentially other participating universities in Australia. The ATC is actively investigating further development of the TTIM™ system to a highly automated and reconfigurable factory system. This new development will concentrate on applied research in improved sustainability (green) principles that are critical to the success of future Australian industry.

The Open Ended Approach

In general, an automated system is developed from two sets of information. First, the engineer requires an understandable set of system requirements, either from verbal description or by some documentation provided by the end user, to formulate a conceptual model of what the system is supposed to do. Second, the conceptual model is interpreted together with constraints that are imposed to the engineer due to physical or financial reasons. In the simplest case, the engineer is constrained by the availability of usable components to design the system. In more complex situations, the engineer can create new components but will be constrained by affordability. This situation is visualized as shown in Figure 3.

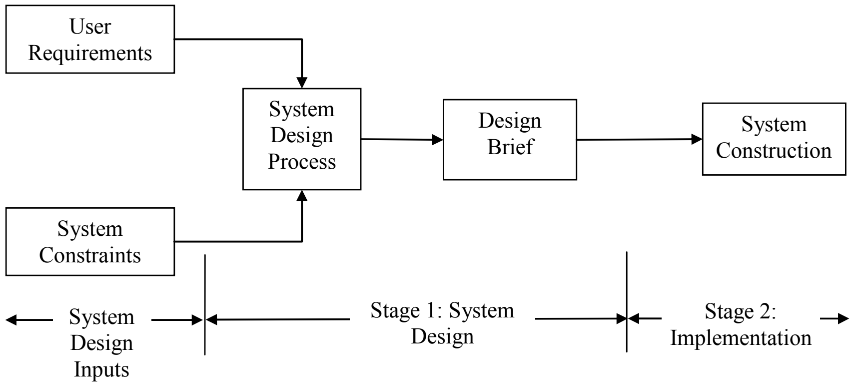

Figure 3: The System Development Process

Since there is no defined working rule of integrating or matching user requirements with system constraints, the system design process is an intuitive and often unpredictable task. Use of system design software such as Robot Studio helps the practical model manipulation aspects of the task but it does not assist the mental development of the system. The worst factor in the system design process is the incompatibility between different hardware platforms. For example, TTIM™ is a highly flexible system. However, its components and system structures are totally different from three mini FESTO systems that are also available in the ATC. Therefore, even though two hardware platforms can both perform similar task, the conceptual development of the system configuration on one platform cannot be re-used or transferred to the second. In other words, the design of the second system which performs the same task as the first but built on a different hardware platform needs to be done from the start.

For engineering students, the goal is therefore not about adapting one system to another, but rather to develop a system design from a task description independent of the platform, and subsequently carry out a matching process that assigns components to achieve the specified function. To achieve this goal, the system development process is divided into 2 stages (Figure 3). This two stage process is illustrated with a simple example of a transfer system.

In this example, the transfer system transports a product from one end to another. The product can be made from different types of material. However, all products have identical shape and dimension. To develop the system, instead of specifying what components on TTIM™ the students should use, user activities and expectations will be provided (Table 1).

Table 1: Transfer system user specification

Step	Description
S1	Product A is placed on one end of the conveyor
S2	The availability of Product A is detected
S3	Conveyor moves
S4	Product A reaches the destination
S5	Conveyor stops

Stage 1 of the system development process requires the students to create a design brief. The design brief is a short document, usually with a lot of sketches (either on paper or using a CAD system) of the conceptual system configuration that they would like to produce. The user specification in Table 1 is an essential reference to this work. The sketches show what components they are going to use (select from the component repository), the actions that the system will take (to the detail of how the product is being sensed and how the conveyor is activated). System activities can be represented by commonly used design tools such as Petri Net (Figure 4).

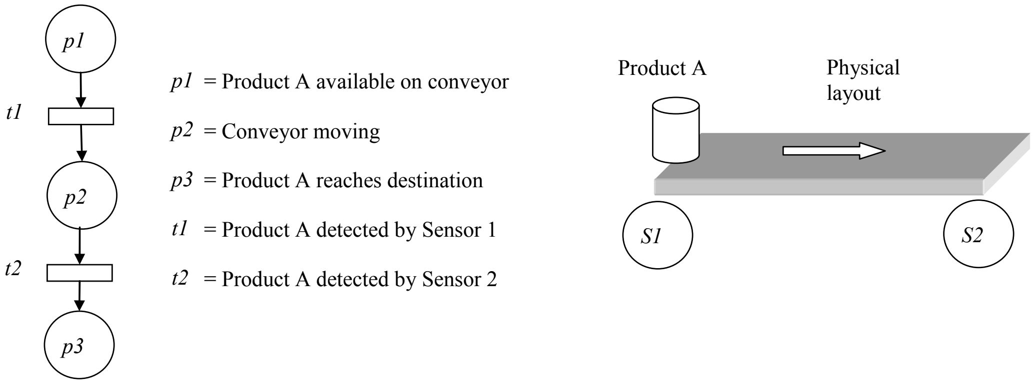

Figure 4: System design using Petri Net

The students will then search for the components that can be used to fulfil the specified user specification. The TTIM™ system comes with a large number of components. In particular, the conveyor TTIM™ allows components to be mounted anywhere on its length (Figure 5). The TTIM™ accessory repository has a number of components including cylinders of different length, several types of sensors, a wide variety of connector tubes, clamps, etc. System parameters such as length of cylinders and sensors are selected from the component repository.

Figure 5: The conveyor and components

The main learning activity is the system design process. Through a studio setting in which the students can freely examine the components and interact with a tutor, the proposed solution is described in a system specification as shown in Table 2.

Table 2: System specification for transfer system

Step	**Description**	**Possible system components**
S1	Product is placed on the conveyor	Operator
S2	Sensor1 senses the availability of a product	Proximity sensor
S2.1	Decision	PLC
S2.2	Indicator ON	Red lamp
S3	Conveyor moves	Motor control
S4	Sensor2 senses the presence of the product	Proximity sensor
S4.1	Decision	PLC
S4.2	Indicator OFF	Red lamp
S5	Conveyor stops	Motor control

The design brief will be presented to a judging panel for approval. Questions will be asked on all aspects including operational and safety issues. The design brief will be reviewed to sufficient detail that there should be no unexpected engineering problem. Once approval is given, the students can proceed to Stage 2.

Stage 2 is about implementation. The system described in the approved design brief will be constructed on the hardware platform, in this case, TTIM™. Obviously, if there are unforeseeable issues, the students may need to spend a lot of time in debugging. The implemented solution will be validated against the design specification in Table 2.

Conclusion

University and industry have to join forces in order to ensure quality education and produce work ready engineering graduates. Establishment of the ATC is a starting point providing a basis for courses to be developed in an industry simulated environment. In order to encourage creativity within a set of engineering constraints, a set of system design activities has been developed based on open-ended user specification that establishes the context of learning. The ATC environment supports the highly interactive, industry like situations. A course experience survey was carried out immediately after the students demonstrated their new systems. Students unanimously endorsed the open-ended approach with comments such as "great learning experience" and "I understand how PLC works". The satisfaction on the course has increased from 66% to 73%. The openness of system design in this context encourages students to become innovative and outcome oriented in the same way as industry practices.

References

Armarego, J., Fowler, L. (2005). Orienting Students to Studio Learning. *Proceedings of the 2005 ASEE/AAEE 4th Global Colloquium on Engineering Education*. 26-30 September, Sydney, Australia

Barbieri, E., Fitzgibbon, W. (2008). Transformational Paradigm for Engineering and Engineering Technology Education. *Proceedings of the 2008 IAJC-IJME International Conference*, ISBN 978-1-60643-379-9, 17-19 November, Nashville, Tennessee, USA

Claxton, G., Edwards, L. (2006). Cultivating Creative Mentalities: A Framework for Education. *Thinking Skills and Creativity*, Vol.1, pp. 57-61

Dutson, A.J., Tood, R.H., Magleby, S.P., Sorensen, C.D. (1997). A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses. *Journal of Engineering Education*, January, pp.17-28

ElMaraghy, H.A. (2006). Flexible and Reconfigurable Manufacturing Systems Paradigms. *Int J Flexible Manufacturing System*, Vol.17, pp.261-276

Gowan, J.A., Mathieu, R.G. (1996). Critical factors in information system development for a flexible manufacturing system. *Computers in Industry*, Vol.28, pp.173-183

Klampfl, E., Gusikhin, O., Rossi, G. (2006). Optimization of Workcell Layouts in A Mixed-Model Assembly Line Environment. *Int J Flexible Manufacturing System*, Vol.17, pp.277-299

Malmqvist, J., Edström, K., Gunnarsson, S., Östlund, S. (2005). Use of CDIO standards in Swedish National Evaluation of engineering education programs. 1st Annual CDIO Conference, 7-8 June, Kingston, Ontario, Canada

Mathur, N., (2007). Mechatronics – Five Design Challenges and Solutions for Machine Builders, *Instrumentation Newsletter*, pub. National Instruments, Q2.

Mo, J.P.T., Simic, M., Dawson, P. (2008). Collaborative Partnership for Development of Mechatronics Engineering Education of the Future, *Proceedings of the 2008 AaeE Conference*, 7-10 December, 2008 Yeppoon, Australia

Ulbrich, A., Scheir, P., Lindstaedt, S.N. Görtz, M. (2006). A Context-Model for Supporting Work-Integrated Learning. *Lecture Notes in Computer Science*. pub. Springer. ISSN 0302-9743. Vol.4227, pp.525-530