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Consolidation of Engineering Education through Industrial Case Studies*

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The early formative years in engineering education are crucial in engendering a professional attitude and weaning students from a high school temperament. Junior students face a range of diverse subjects, involving various faculties, with seemingly minimal connections between them. For effective problem-solving, it is necessary to have an integrated cognitive structure for flexible retrieval and application of acquired tools. Students often fail to see the relation between the early courses and their chosen professional discipline. To encourage integration, we started the practice of collaborating with other course instructors of concurrent courses, to set a single joint project to count for both courses. The project, often with variations for each group, is carried out in small groups. The presentation of analyses and results provides opportunities to improve verbal and writing skills. We found that the exercise fosters a better understanding of relation between courses and an appreciation of the structure of the discipline during the formative stages of education. This article highlights the problems of fragmentation in engineering curricula, the remedial measures we tested and the results of our efforts.

INTRODUCTION

STUDENTS OFTEN do not recognise all of the links between courses in a curriculum. This is particularly experienced with the widely adopted semesterised system. The university curricula could be compared to construction of an educational (undergraduate) platform on support systems (courses). If those in charge (professors) of constructing the support do not communicate often with each other and the students, the students responsible for constructing the platform are left to their own devices and may find constructs of incompatible and unsuitable forms and models. With a courseware design having interconnections, the links between courses can be made explicit and the delivery co-ordinated such that the boundaries between courses are more transparent to the students.

Studies [1, 2] show that especially during the early formative years in engineering education, there are significant needs in fostering a professional attitude and in disengaging students from a high school temperament. The early years constitute periods of transition for many students, coming from a secondary education background. In addition to making adjustments to a new operating philosophy and social environment, students academically are confronted with a diverse range of subjects, involving various faculties, with seemingly minimal connections between them. This practice frequently results in substantial segregation between courses and a disposition towards rote memorising, which in turn can result in loss of associative learning in the initial stages.

Engineering education traditionally places emphasis on 'exposition' followed by 'application', within the domain of a specific course. Subject matters are programmed such that the general ideas of the discipline are presented initially, and then progressively differentiated in terms of detail and specificity.

Often the exposition and application phases dominate the treatment, while integration (see Fig. 1) between courses receives scant attention for a major part of the coursework-related education. Engineering curricula often allow fragmentation of concepts to such an extent that students have difficulty in integrating these concepts to solve complex problems even after graduation. With the current urgency to provide a well-rounded learning experience, abilities in addition to conventional engineering skills are being stressed at all levels in academia, including the early formative years of engineering education.

A typical engineering teaching plan consists of the following elements:

- exposition of scientific principles;
- exposition of engineering principles;
- acquisition of practical and theoretical skills;
- application of acquired skills to complex problems.

Teaching of courses is then followed by appropriate assessment and feedback.

A systems analogy version of traditional education in terms of the stimulus, response and feedback process is depicted in Fig. 2.

An important detail missing from this approach

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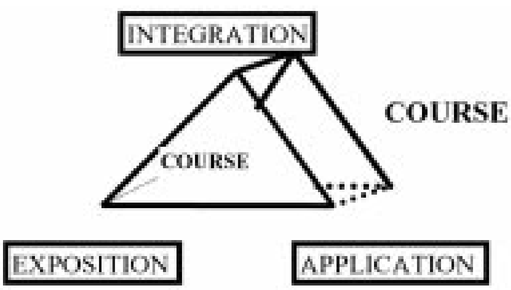

Fig. 1. Dimensions of learning.

relates to the multi-dimensional nature of learning and consequently the multivariable structure of the education process. Further, any significant application phase usually takes place towards the end of the curriculum (in the form of design and thesis), often long after the principles have been taught. If we recognise that all aspects of learning should be interrelated, then educators need to explore appropriate integrative learning tools to avoid excessive fragmentation and foster interaction among the participants [3–6].

Student-centred learning fundamentally shifts the balance between learning inside and outside the classroom. With shared projects encouraging co-operative learning, students have access to greater informational resources and learning styles through their peers, more than a single instructor and tutors. Material traditionally covered in class can be introduced, at least at the lower levels in Bloom's Taxonomy, through student-tutor group interactions. Instruction in the classroom can focus more on the underlying concepts and less on the regurgitation of raw facts. The requirements of good written and oral communications for the project encourage more student-centred focus.

This article highlights the dangers of excessive fragmentation in course presentation even at the early stages of engineering education and that lack of relating between courses could create compartmentalisation of knowledge. Our attempts at including integrative elements between courses and encouragement towards co-operative learning are discussed.

DEVELOPING A CONSOLIDATION TECHNIQUE

Science subjects dominate early engineering courses such that key principles are introduced

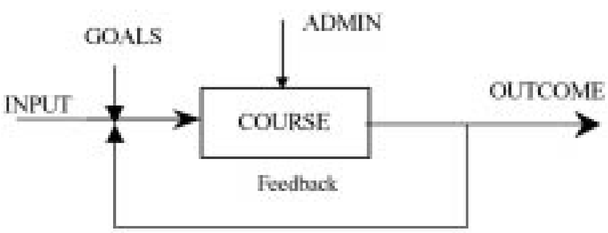

Fig. 2. Conventionally controlled learning process.

for development of applications later on. However, the early science and engineering courses are conducted often with little or no effort towards cross-program interrelation.

For effective problem solving, it is necessary to have an integrated understanding of the available tools for flexible retrieval and application later. Thus, the usual convenient practice of segregating disciplines into courses and sub-courses with little interrelation is often insufficient for deep learning. Courses offered in parallel or in sequence, provided for ease of digestion in a semester system, often appear to be confined within their compartments to serve their specific purpose, as little time is spent on venturing into related territories.

Such methods may be responsible for eliciting student responses such as: '. . . that was taught in Heat Transfer—are we supposed to know it for Mass Transfer?' A message that needs to be emphasised early on is that engineering as a body of knowledge has structure and form, is built upon fundamental laws, concepts and data that we believe are self-consistent and integrative. Our discipline is not an unrelated collection of a few thousand equations put together to solve problems in a 'cook-book' manner.

Students need to be guided to avoid missing the big picture in the presence of details. Students often do not see relationships between concurrent courses, but view them as separate entities. Often the perception exists that lessons learnt in a particular subject will not come under a rigorous test in a different course. This implies that the provision of a 'road-map' of the discipline showing links between different courses and how they fit in is required.

Students continue solving problems of manageable dimensions within specific courses for the major part of their undergraduate education. Thus crucial connective links between different courses remain unexplored. The consequence is a distorted view of real-life problems. Meaningful learning can be greatly facilitated by relating what is known to students with solving open-ended problems. The lack of understanding of the course structure at the early stages of education often results in loss of motivation and interest among students. Mainly at the final stages of a degree program, senior advanced students have opportunities for integrating their learning through thesis and design work, that involve challenging open-ended problems, encouraging motivated effort.

The rigid early segregation between courses implies that methods memorised to solve typical problems for respective courses, would not be flexibly available for solving open-ended real-life problems. Thus integration is important not only within a course (intra-course) but also in relation to the discipline and concurrent courses. Hence integrative mechanisms are key to holistic education, following detailed expositions in concurrent courses. Shaeiwitz [6] also presented a paradigm for design education through the integration of design throughout the undergraduate engineering curriculum.

IMPLEMENTING CONSOLIDATION TECHNIQUE

In order to encourage course integration three years ago, we started the practice of collaborating with other course instructors within our department to set a single joint project that would count for both courses. The final project is normally carried out in small groups, often with minor technical variations for each group, thus encouraging cross-fertilisation within and between the groups. The presentation of results through formal reports and orally, provide further opportunities to improve verbal and writing skills.

At the University of Sydney, we offer Material and Energy Balances (Chem Eng 1) and Process Case Studies during the first year. Chemical Engineering Computation, Fluid Mechanics and Heat and Mass Transfer (Chem Eng 2) are offered during the intermediate (or second) year. These courses focus on the fundamentals of conservation principles, detailed analyses of transport processes, process analysis and process design principles. The remaining courses involve other faculties. We decided to set joint end-of-course projects for courses offered in our department to highlight the lessons learnt in each of the courses and also combine elements from each course to solve a significant engineering problem.

Our course schedule permitted setting a joint project on early process design (e.g. bio-refinery design) for Chem Eng 1 and Process Case Studies during the first year and on fluid flow and heat transfer analyses for Chem Eng 2 and Chemical Engineering Computation during the intermediate year. Our objectives were to:

- attempt integration between two courses;
- solve a non-trivial engineering problem;
- provide early analysis and synthesis experience;
- encourage team effort.

Typically the classes were divided into groups having four to five members, composed of weak, average and strong students (based on the latest grade point averages). The groups were drawn from concurrently offered courses. Often a handful of students (6–8) were not part of one or the other course so these students were distributed across groups such that there were at least three members taking both courses. The management and task allocation were left to the group members to arrange.

Opportunities were provided for the group members to meet during the tutorial hours and on their own. Every group member was asked to assess their peers' efforts (scale of 0–10) and indicate the actual contribution of each group member in a section entitled 'Who did what' for attachment with the final submission. The individual group members were monitored by the lecturers and tutors during the tutorial and class hours assigned for the project. At the conclusion of the project, the team members were questioned on the technical aspects of the project such that team members were individually held responsible for the entirety of the project content. These inputs formed the basis for awarding a final mark to an individual student.

Initial instructions were provided on how to function in a team and support was offered to help teams function effectively. In general, the groups were organised to promote student communication with minimum staff intervention. The students approached the problem through internal co-ordination, sharing of common difficulties and insights, encouraging weaker students, fostering a sense of responsibility, accountability and creation of memorable situations. The average duration of the shared project was about three to four weeks before the termination of the semester and the projects were typically assessed at fifteen percent of the total course marks for each of the courses.

An example of one of our problems, the conceptual design of a *bio-refinery*, is summarised in the appended *case study*. Figure 3 summarises an exemplar in process synthesis (with groupwise variations), learnt and developed by students during the project. The problem was intended to facilitate consolidation of lessons learnt in two concurrent courses: one based on detailed expositions of engineering principles and the other oriented towards the study of overall processes.

The main objectives in solving the problem were to:

- conceptualise an entire manufacturing process given only basic information;
- select appropriate process equipment to carry out required operations;
- develop a process flowsheet, after sequencing and positioning the selected equipment;
- carry out detailed balance calculations for process engineering;
- research and answer the open-ended questions posed;
- collaborate with the team to solve the sub-problems;
- learn team-work and hone communication skills.

EXPERIENCE WITH CONSOLIDATION

The integrative exercise of 'shared course projects' has been carried out over a three-year period for the first and second courses mentioned above. The problems selected with components from each course are relatively large to provide greater challenges than those selected from the confines of a single course. A side-benefit of the

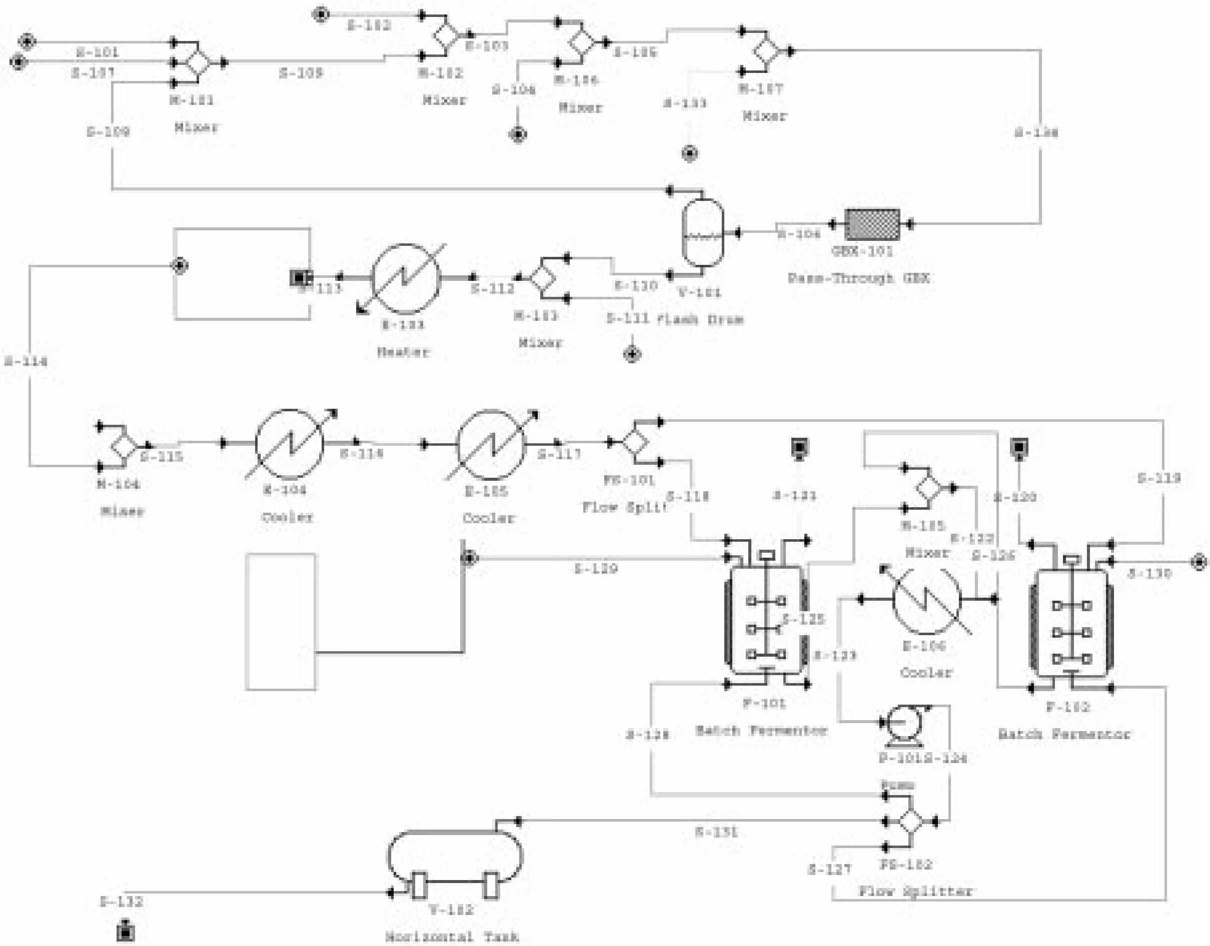

Fig. 3. Excerpt from developed manufacturing flowsheet.

shared project was that the time and effort needed for the lecturers and tutors for the two courses were optimised and no additional time allocation was needed.

The students found the problems challenging and stimulating, but not overwhelming. The groups functioned better than satisfactory in achieving their objectives as very few conflicts were noted. Conflicts relating to communication were resolved through encouragement of mutual phone-calls and sending of e-mails. Lack of responsibility by any individual was assessed through low grade. The fact that group members needed to co-operate for a common goal engendered a degree of independence and responsibility for the project. Our experience indicated that the majority of the teams functioned without major complaints, knew what the other team members were doing and displayed a satisfactory level of understanding.

A majority of the students indicated that the project work helped them gain an understanding of how their fellow students think and work: 'I not only got to know how I think and solve problems, but I also realised the assumptions made by my partners'. The students also gained experience on how to cope with deadline pressures and peer reviews. The students spent more time on the project than they anticipated, expressed satisfaction on completing the project, and considered it a memorable experience. The feedback from the course evaluations showed improved satisfaction with the courses (about 10–15 percent greater satisfaction ratings were noted). The carry over from the experience to subsequent years was found in the form of better appreciation of the principles learnt.

The exercise provided a mechanism to synergise greater curriculum integration, minimise compartmentalising, strengthen cross-disciplinary learning, improve the social aspects of intellectual development, gain support of fellow collaborators in a new environment and reduce anxieties in meeting submission deadlines for different courses. The distributed learning process also encouraged variations in approach and ways of learning, such that the students were not subjected to a single prescribed mode throughout. The format of these projects could also be derived from a larger research project to enhance the challenge and allow the direct flow of research work into teaching.

CONCLUSIONS

Tackling challenging problems with group-based learning could foster deep learning and understanding within the discipline during the formative stages of education. The integrative learning experience can help in the following ways:

- Provide students with the option of being involved in structuring their own learning experiences.
- Teachers act as facilitators and resource persons rather than dispensers of information.
- Students develop both initiative and technical skills needed to work co-operatively with their peers.
- Opportunities exist in developing communication skills.
- Students self-assess by evaluating their own and each other's work critically.
- Students develop confidence in tackling challenging problems.
- Students with lower competency have the opportunity to reach the competency level of their peers.

Group projects require effort from both students and instructor. Due to the lack of in-class time, often a substantial part of the work is done out-of-class. The instructor, not the teaching assistant, must assess the quality of the deliverables and provide feedback, which is challenging. However, the extra effort is worthwhile. An overwhelming majority of the students appreciate the group experience, learn communication skills and technical matter from their fellow group members. For the instructor, the group projects provide an additional avenue of communication with the students that gives the instructor the opportunity to know the students better.

Through positive intervention in encouraging integration between courses, we may avoid the ill effects of compartmentalising knowledge. Research on co-operative learning is summed up succinctly by Wells, *et al.* [7]: '. . . to achieve most effectively the educational goal of knowledge construction, schools and classrooms need to become communities of literate thinkers engaged in collaborative enquiries.'

REFERENCES

1. C. McInnis, R. James, and C. McNaught, *First Year on Campus*, Canberra: Australian Government Publishing Service (1995).
2. J. R. Dalziel, and M. Peat, Fostering collaborative learning during student transition to tertiary education: an evaluation of academic and social benefits, in C. Rust, ed., *Improving Learning*, Oxford: Oxford Centre for Staff and Learning Development, (1998) pp. 272–283.
3. E. Aronson, *The Jigsaw Classroom*, Sage, California: Beverly Hills (1978).
4. W. Doise, and G. Mugny, *The Social Development of Intellect*, New York: Pergamon Press (1984).
5. D. W. Johnson, R. T. Johnson, and K. A. Smith, *Cooperative Learning: Increasing College Faculty Instructional Productivity*, Washington, DC: ASHE-ERIC Higher Education Report (1991).
6. J. A. Shaeiwitz, Teaching Design by Integration Throughout the Curriculum and Assessing the Curriculum using Design Projects, *Intl. J. Eng. Educ.*, **17** (4/5), (2001) pp. 479–482.
7. G. Wells, G. L. M. Chang, and A. Maher, in S. Sharan, ed., *Cooperative Learning: Theory and Research*, New York: Praeger (1992) pp. 1–22.
8. R. M. Felder, and R. W. Rousseau, *Elementary Principles of Chemical Processes*, 3rd Edn, New York: Wiley (2000).
9. J. Van*, Engineering and Technology Review*, p. 5, September, 1998.

APPENDIX

Case study: designing a bio-refinery

Purdue University (West Lafayette, Indiana, USA) researchers have taken the same yeast that ferments grapes into wine and transformed it into a superbug with an appetite for grain kernels, grain stalks, wood chips and other organic waste that it converts to ethanol. Molecular geneticists claim that instead of just using corn kernel, it will now be feasible to use corn stalks and other waste material for producing ethanol. Purdue's superbug squeezes 30% more ethanol from biomass because it has been engineered to expand its traditional diet [9].

In a number of countries, such as USA and Brazil, considerable progress has been made in using ethanol to supplement gasoline. In addition, the abundance of grains produced in USA, Australia and other countries has enhanced the attractiveness of converting a portion of these grains and production wastes to ethyl alcohol for blending with gasoline as an octane enhancer (instead of adding polluting chemicals such as benzene, toluene, xylene, MTBE, etc), or for use as a feedstock in the synthesis of other chemicals.

Your company is considering a bid to purchase an ethanol production plant owned by a smaller company. As the company's Chief Process Engineer, you have been assigned to review the process. This review is to include a quantitative study of the operation and should develop detailed information regarding key process variables. Although the study need not be concerned with economics, consideration should be given to the energy requirements of the process. Suggestions for alternative processing schemes should also be considered.

In the process to be described, a portion of the starch in corn is converted to ethyl alcohol by two biological processes: (a) saccharification and (b) fermentation. In saccharification, the polymeric structure of starch (a polysaccharide) is hydrolyzed in the presence of the enzymes (biological catalysts) α-amylase and amyloglucosidase. The primary products of hydrolysis are maltose (a disaccharide consisting of two glucose units) and oligomers consisting of several glucose units.

The alcohol plant under consideration is designed to produce 100×10^6 L of 199-proof (99.5 vol %) ethyl alcohol per year. Existing technology provides a yield of 10 L of alcohol from a bushel of corn. The process is to be operated continuously, with the exception of the fermentation and fungal amylase sections of the plant, which must be operated in a batchwise fashion to allow for frequent sterilisation of equipment. The plant will operate at least 330 days per year. Details on the process may be obtained from the Internet and literature source [8].

Questions

In your answers to the following questions, cite all sources of data, references and clearly state all assumptions:

1. Construct a flowsheet of the overall process and a diagram of a fermentation battery containing two reactors, a pump and a heat exchanger. Calculate and fill in the flow rate and temperature of each stream to the extent possible from the given information.
2. Estimate the feed rate of corn and the acreage required to supply the biorefinery with corn (according to the Department of Agriculture 101.2 bushels of corn are harvested from an acre). Estimate the molar flow rate of ethanol product and of water (fresh water and condensates) that must be added to the mixing tank to obtain the desired mash volume.
3. What is the minimum pressure at which the cooking vessel must operate? What is the pressure to which the mash must be flashed to provide a resultant liquor temperature of 63ºC? At what rate is water vaporised in this step? Determine the rate (kg/h) at which 2 atm steam must be supplied to heat the mash from the precooking vessel to 110ºC. How much live steam must be injected to raise the temperature of this stream to 160ºC? It has been suggested that a portion of these steam requirements could be met by the vapour from the flash occurring at 2 atm. Is this feasible?
4. The efficient use of energy is an important consideration in the economics of the process. Estimate the total amount of heat that must be removed from a single fermenter for the temperature to rise as indicated and then to level off at 35ºC. At what rates must heat be removed to condense vapour streams from each of the distillation columns and the stripper? At what rates must water be supplied to each condenser? Steam imports may be reduced by using vapour from the ethanol concentrator to provide heat to the reboilers on the azeotrope column and the stripper. Furthermore, it has been proposed that the vapours from the columns and the stripper be condensed by providing heat to the feed and recovery system. Is this feasible? Attempt to balance the steam and water requirements within the plant by utilising available streams.
5. A number of alternative processes for the synthesis of ethanol use nonbiological feedstocks. Summarise the chemistry of two such processes and compare them with the biosynthetic route.

CO_2 produced in the fermenter may be useful if it is recovered as a by-product in sufficient quantities. Estimate the plant production rate of CO_2 and suggest at least six feasible routes for disposing the greenhouse gas, CO_2, produced during grain fermentation.

Vincent Gomes received his M.Eng. and Ph.D. degrees from McGill University, Montreal, and his B.Tech. degree in Chemical Engineering from IIT. He is currently a faculty member at the Department of Chemical Engineering and Program Manager of the Australian Key Centre for Polymer Colloids at the University of Sydney. He has worked in petrochemical and pulp and paper industries as a process engineer. His current research focus include polymer engineering, sorption and reaction processes and sustainable development. He has strong interests in making teaching and learning rewarding experiences for all concerned.