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Collaborative Learning in Engineering Education*

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Collaborative learning has been defined in a number of ways, but is generally understood to refer to small group learning where the group members actively support the learning processes of one another. Collaborative learning is increasingly recognised as giving students an opportunity to engage in discussion and to exercise a positive influence on the group's learning outcomes by assuming responsibility for their own learning. Critical thinking and reflective evaluation are implicit in the approach. In this article, the authors reflect on these general aspects and discuss their own experiences in employing *collaborative learning* techniques in their teaching. These include group work in laboratories, short-term team projects in engineering courses and capstone team projects in the final year of the programme.

INTRODUCTION

The notion of collaborative learning alludes to learning within groups that have been formed for the specific purpose of achieving set educational goals. Groups are small, normally not exceeding five members, and are purposed to be conducive to achieving a successful learning outcome that may be demonstrated by the acquisition of knowledge and skills or the completion of a set task. Collaborative learning has been hailed as giving *students an opportunity to engage in discussion, take responsibility for their own learning, and thus become critical thinkers* [1][2].

The main domain of application of collaborative learning seems to have been in primary and secondary education for which there is a mature research base. However, the well established principles are equally – even more aptly – applicable to tertiary education, especially so in the case of engineering education. Yet the body of literature reporting research outcomes/experiences from tertiary education appears modest in comparison [3].

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COLLABORATIVE VERSUS *COOPERATIVE*

There has been a lively debate about the *tag* attached to the learning paradigm that involves the active participation of *learners* in a small group towards achieving learning outcomes [4]. Is it *cooperative* learning or, more aptly, *collaborative* learning?

The dictionary definitions of these terms are as follows:

- Collaborate = work jointly (from Latin *collaborare*);
- Cooperate = work or act together (from Latin *cooperari*) [5].

So it should come as no surprise that there is some *murkiness* in the use of the terms to describe the object of the paradigm [6]. It has been argued that:

> *Collaboration is a philosophy of interaction and personal lifestyle whereas cooperation is a structure of interaction designed to facilitate the accomplishment of an end product or goal* [4] (underline added by the authors for emphasis).

The authors of this article confess to having succumbed to the *fuzziness* or *murkiness* of the difference between the words, both of which describe individuals *working together with the intent of enhancing learning outcomes for all involved* and hence will adopt the adjective *collaborative* with reference to small-group learning in discussing the notion further in this article.

Of further note is the use of the word *group*, which will be used alternately with the word *team* to denote a small number of individuals joined together for the pursuit of a common goal.

Notwithstanding the semantic nuances, both tags signify a major change from the previously prevailing learning paradigms, shifting the responsibility for learning from the teacher to the learner in a *team* united in purpose to improve learning outcomes however they are defined.

SO, WHAT IS *COLLABORATIVE LEARNING*?

There seems to be a plethora of views as to what constitutes *collaborative learning*. These range from the notion of small group learning [4] to learning within the confines of a class and beyond, exceeding the boundaries of local teaching and learning entering into the domain of distance learning where the computing and information technology increasingly assume a dominant importance [7][8]. For the purposes of this article, the authors adopt the definition of collaborative learning as being a learning approach, which favours deep learning within a small team environment, where the individual team members unselfishly strive to contribute their utmost towards achieving the best learning outcomes for the team. In a way, this smacks of the principles of comradeship embedded in the dictum *Unus pro Omnibus. Omnes pro Uno*. This unofficial motto of Switzerland is equally cherished and valiantly advocated in many parts of the world, especially in Europe and North America (Figure 1).

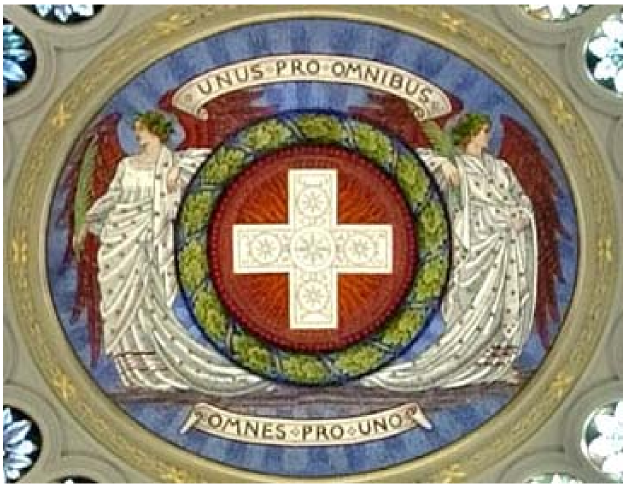

Figure 1: The notion of *collaboration* as depicted on the dome of Swiss Parliament [9].

It has been postulated that there are five major elements in this type of *team* learning, namely:

- Positive interdependence;
- Promotive interaction;
- Individual accountability;
- Use of interpersonal skills;
- Monitoring of progress [10].

Positive interdependence alludes to the belief that the group can succeed if all group members pull their weight towards achieving their common goals. *Promotive interaction* ensures that group members encourage and help one another to move forward. On the other hand, every member of the group is responsible and *individually accountable* for the group's learning outcomes whichever way they may have been defined. Evidently, *interpersonal skills* are critically important to the success of the group's endeavours: to succeed as a group, the members must trust and respect one another, communicate well and know how to handle conflict. For the group to have a genuine sense of achievement, there has to be some serious monitoring of progress based on achieving the milestones in a realistic schedule of activities agreed upon by the group and sanctioned by their *teacher* [10].

So, in a nutshell, when collaborative learning is adopted, competition is out and collaboration is in! This may sound as if the collaborative learning paradigm does not provide an environment for growth for the exceptionally talented, but that is not so! This is because those with greater talent than the rest still thrive by being a leading influence on their peers in the team. Furthermore, competition between several groups provides another proving ground.

WHY DOES IT WORK?

Cooperative learning works for more than one reason. Firstly it engenders a *team spirit* in members of the group. This motivates the more capable students in the group to help those struggling with the concepts. Similarly, the less able students develop a consciousness that they owe it to the team to pull their weight – so to say! Also, while helping their weaker team members, those with a better grasp than the rest may discover that they need to add to their knowledge for greater mastery. This in turn may inspire others in the group to widen their knowledge base. The shared responsibility for the team's destiny may compel everyone in the team to meet their obligations in terms of meeting assessment deadlines whether it be reports, milestones or other deliverables. Furthermore, cooperative learning is firmly based on *doing*! As such, it constitutes *active learning* [11].

RELEVANCE TO ENGINEERING EDUCATION

It is arguable that

> *… the advances in technology and changes in the organisational infrastructure put an increased emphasis on team work within the workforce. Workers need to be able to think creatively, solve problems, and make decisions as a team* [1].

Interestingly, this is exactly how engineers practise their profession! The notion of *collaborative* work is inextricably anchored in engineering practice. By and large, engineers do not work in isolation. It is inconceivable to think that great engineering projects of high complexity, whether it be a rapid transport system or satellite communication network, can be conceived and created by an engineer in solitude. Consequently, *collaborative learning* is most suited and a natural must in preparing engineering students for the challenges that lie ahead.

CHALLENGES

Despite the anticipated benefits of collaborative learning approach, engineering educators have to be prepared for a number of challenges when adopting collaborative learning strategies. They must appreciate that students entering into university engineering programmes come from vastly different educational, cultural and personal backgrounds. Students will have their favourite learning styles and will process the information they receive in different ways which must be accounted for.

Setbacks are inevitable once the collaborative learning paradigm has been adopted as the main stay of teaching and learning [11][12]. If a group is wavering, it is best to continue to provide as much support as is reasonable. This involves maintaining close contact with the group, making sure that the group has clearly defined goals, monitoring progress and inculcating self discipline as a prime ingredient for success. As a last resort, a *team leader* may be appointed.

BENEFITS

There is arguably a substantial number of benefits to be derived from adopting a collaborative learning strategy in education. First of all, the participants *learn to learn*. They acquire the skill of critical thinking, along with enhanced motivation, shared responsibility for learning, and learning by all, including the teacher, all of which contribute to building confidence and self esteem. Teamwork provides a better understanding of the subject for team members, providing stimulation in the thinking process. Shared responsibility for producing the group's deliverables has the effect of reducing the anxiety linked to the task. The right dose of humour is also seen to have stress reducing effect for the team members.

Evaluations of the effectiveness of the collaborative learning approach in university programmes in science, mathematics, engineering and technology programmes encourages its more widespread implementation [1][13].

SOME NEGATIVES

Some negative experiences are also noted that stem from personality clashes and irresponsibility within groups. For instance, group decision-making can be dominated by individuals with strong personality traits who can persuade by talking loudly and long, which can possibly intimidate the group members with a more subdued personality. This would be contrary to one of the basic tenets of collaborative learning that everyone must be given an opportunity to contribute to the group's learning outcomes [1].

Adopting the collaborative learning mode may also lead to strong opposition and resistance on the part of some students. This is particularly the case if groups suffer from disparity.

Students with better scholastic and intellectual aptitudes may feel that their progress is retarded due to lack of worthwhile contribution from the weaker team members. The latter may become disheartened and feelings of inferiority may surface. All this may put the teacher under pressure to abandon the approach and to go back to the traditional lecture-based delivery of the course materials. This would constitute a regrettable loss for both the teacher and the learners [11].

TENETS OF COLLABORATIVE LEARNING

Tenets of collaborative learning are based on shared goals, teamwork, a willingness to keep learning, individual responsibility and self-discipline. Interestingly, these tenets are inclusive in the educational framework at the authors' own university, the University of South Australia (UniSA) in Adelaide, Australia, which has articulated a set of seven Graduate Qualities to be inculcated in its graduates as distinguishing characteristics. A graduate of UniSA:

1. *operates effectively with and upon a body of knowledge of sufficient depth to begin professional practice*
2. *is prepared for life-long learning in pursuit of personal development and excellence in professional practice*
3. *is an effective problem solver, capable of applying logical, critical, and creative thinking to a range of problems*
4. *can work both autonomously and collaboratively as a professional*
5. *is committed to ethical action and social responsibility as a professional and citizen*
6. *communicates effectively in professional practice and as a member of the community*
7. *demonstrates international perspectives as a professional and as a citizen* [14].

The University of South Australia was a forerunner in Australia in the development of a set of generic graduate qualities as early as in 1995. As indicated in Table 1, these *qualities* match remarkably well with the ten *generic attributes of a graduate* formulated by the Institution of Engineers, Australia (the accrediting body for engineering programmes in Australia) and the 11 *EC2000 Criterion 3 outcomes* of the Accreditation Board for Engineering and Technology (ABET) in the USA [15][16].

It stands to reason that collaborative learning provides the tools towards achieving a number of these qualities. Indeed, several of the above listed qualities are implicitly embraced in collaborative learning.

More recently, the notion of *collaborative learning* has been extended into the realm of *distance learning* due the rapid developments in computer technology and IT. Networked Computer-Aided Learning (CAL) strongly augments collaborative learning and its further proliferation into the domain of collaborative learning is a foregone anticipation.

Table 1: Mapping of UniSA Graduate Qualities with IEAust Generic Graduate Attributes and ABET Criterion 3 Outcomes [14-16].

UniSA [14]	IEAust [15]	ABET [16]
Body of knowledge	Ability to apply knowledge of basic science and engineering fundamentals (IEAust 1) In-depth technical competence in at least one engineering discipline (IEAust 3)	Ability to apply knowledge of mathematics, science and engineering (ABET a) Ability to design and conduct experiments (ABET b) Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET k)
Life-long learning	Expectation of the need to undertake lifelong learning, and capacity to do so (IEAust 10)	Recognition of the need for, and an ability to engage in, life-long learning (ABET i) Knowledge of contemporary issues (ABET j)
Effective problem solver	Ability to undertake problem identification, formulation and solution (IEAust 4) Ability to utilise systems approach to design and operational performance (IEAust 5)	Ability to design a system, component and process to meet desired needs (ABET c) Ability to identify, formulate, and solve engineering problems (ABET e)
Work alone and in teams	Ability to function effectively as an individual and in multidisciplinary and multicultural teams, with the capacity to be a leader or manager as well as an effective team member (IEAust 6)	Ability to function on multidisciplinary teams (ABET d)
Ethical action	Understanding the principles of sustainable design and development (IEAust 8) Understanding of professional and ethical responsibilities and commitment to them (IEAust 9)	Understanding of professional and ethical responsibility (ABET f)
Effective Communication	Ability to communicate effectively, not only with engineers but also with the community at large (IEAust 2)	Ability to communicate effectively (ABET g)
International perspective	Understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development (IEAust 7)	The broad education necessary to understand the impact of engineering solutions in global and societal context (ABET h)

COLLABORATIVE LEARNING AT THE UNISA

The authors have employed the collaborative learning paradigm in their own teaching at the UniSA. The modes they used have included, *inter alia*:

- Group work in laboratories;
- Short-term team projects in engineering courses;
- Capstone group projects in the final year of the programme.

Project-Based Laboratory Work

At the School of Electrical and Information Engineering (EIE) at the UniSA, traditional laboratory work involving a sequence of practical sessions in the course *Introduction to Electrical Engineering* has been replaced by project work. In this first semester course in the first year of the programme, groups of two to three students are given the task of producing an operational piece of equipment, currently an electronic power supply (Figure 2). This necessitates familiarisation with the underlying theory and existing practices, getting to know the components, and developing manual skills such as soldering and assembling. The fundamentals were covered during scheduled formal lectures.

After final assembly, the power supply is tested to ascertain compliance with the system specifications. As a sequel, the power supply thus produced is used in the follow-up course, *Principles of Computer Systems*. This provides an additional incentive to the collaborative learning process since the evidence of success is practically demonstrable beyond the term of the effort. In addition, this experience early in the programme constitutes a critical stage in the successful transition to university studies.

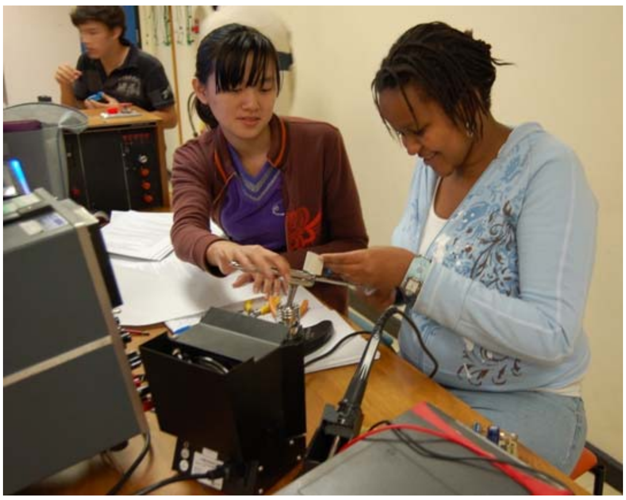

Figure 2: A project-based laboratory.

Coursework Projects

A collaborative learning framework is the basis for a number of postgraduate and advanced undergraduate courses in the programmes offered by the School of Electrical and Information Engineering at the UniSA. In these, groups of up to five students work together on a class project. Groups are formed either by the course coordinator on his/her discretion or by the students. Even when the groups are formed by the course coordinator, students' views and wishes are taken into account in group formation. Special emphasis is laid on group heterogeneity, considering such factors as gender, ethnicity, socio-economic background, academic ability and practical skills.

As an example, assessment in mechatronics courses in the Electrical and Mechatronic Engineering stream is mainly based on the completion of a project that requires a mobile robot to be designed, built, tested and demonstrated. Students working in groups of three to five have some 11 weeks during which to conceptualise, design, manufacture and test their robot before they demonstrate it in competition with other teams. Teams have to employ engineering skills and system design techniques towards achieving their goal. The objective and the competition rules vary from year to year. They are jointly decided with participation by the whole class and form the basis of grading of the groups' efforts. All groups take part in the peer assessment of the oral presentation and robot performance on the day of competition (Figures 3 and 4).

The results have been encouragingly and consistently positive. Students enjoy the latitude they are given in developing their learning outcomes collaboratively and evidence it by quality achievements. This has been confirmed by student evaluations.

Figure 3: A group of students with their mobile robot on competition day.

Figure 4: Setting up a mobile robot for demonstration.

Final Year Projects

Final year projects constitute the *capstone* in the four-year degree and five-year double degree programmes run by the School of EIE. These are undertaken collaboratively by groups of normally three students over two study periods of 13 weeks each. Students either choose their topic from a list of mainly multidisciplinary projects or initiate a project to match their own interest and aspirations. A brief project specification is produced for each proposed project, which includes an initial problem statement, skills required, resources available, and sponsor and contact details for further information. Alternatively, the group may develop the project topic in consultation with an industry sponsor. Some 80% of the projects in the School of EIE are industry sponsored with intense involvement with the industry supervisor.

Both the project choice and group formation are subject to negotiation and approval. Once approved, students have a great deal of autonomy and access to resources including manufacturing assistance, albeit under a strict regime in that all processes are to be based on systems engineering principles and standards. Teams must meet regularly, by themselves and with their supervisors, they have to keep formal meeting records, and must maintain a logbook. Each team must submit a project plan at the end of the fifth week which must contain an assessment agreement, statement of work to be undertaken, a project schedule, cost analysis, product testing method, system deliverables comprising documentation and the product, risk management and the group's organisational structure describing the individual responsibilities of the team members.

As a rule, teams work well and produce quality work, which is often taken up by industry partners for further development. An example is that of the design, manufacture and commissioning by a group of three final year students of a giga-Hertz transverse electromagnetic (G-TEM) cell for electromagnetic interference measurements (Figure 5).

CONCLUSION

The collaborative learning approach is intrinsically linked to many of today's highly held educational paradigms touted as the *world's best practice*. Such include active learning, student-centred learning, problem-based learning and project-based learning. Upon closer scrutiny, one can not avoid the inevitable conclusion that *collaborative learning* is the obvious natural choice for engineering education.

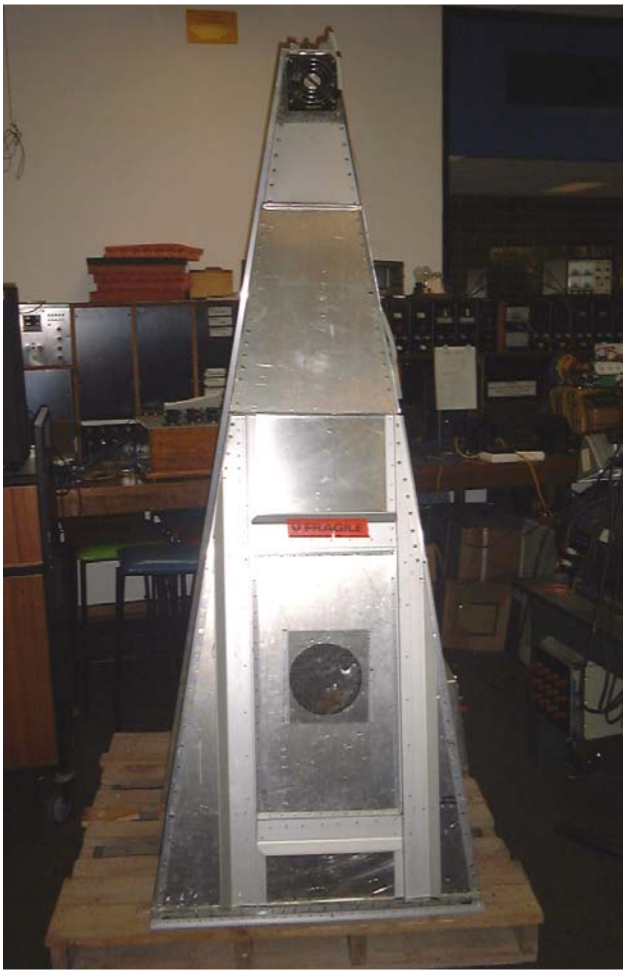

Figure 5: The completed G-TEM cell.

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BIOGRAPHIES

Özdemir Göl has had extensive experience as an engineering educator in addition to his substantial industrial experience. His academic career has included appointments in electrical engineering at universities in Turkey and Australia. He is the holder of MESc, ME and PhD degrees, all in electrical engineering. He is currently Associate Professor and discipline head of Electrical Engineering at the University of South Australia. His research interests have been focused on electrical machines and drives, and include the modelling and simulation of electrical machines using numerical methods and application of mathematical techniques to design the optimisation of electromagnetic devices. He is particularly interested in the design and development of novel electromechanical energy conversion devices, which integrate emerging active materials and non-conventional topologies.

He has a strong interest in innovative approaches to engineering education and has published widely in this field. His teaching responsibilities have included courses in electrical machines, engineering design and virtual instrumentation. He is the author and co-author of some 200 publications and recipient of numerous national and international awards of excellence for his work.

Andrew Nafalski's career spans several decades in academic and research institutions in Poland, Austria, the UK, Germany, Japan and Australia. He holds BEng(Hons), GradDipEd, MEng, PhD and DSc degrees. He is a Chartered Professional Engineer and Fellow of the Institution of Engineers, Australia, Fellow of the Institution of Engineering and Technology (UK), Senior Member of the Institute of Electrical and Electronic Engineers (USA) and Honorary Member of the Golden Key International Honour Society. He is currently a Professor of Electrical Engineering at the University of South Australia in Adelaide, Australia, and Professor of Information Technology and Computer Science at Lublin University of Technology, Lublin, Poland.

His major research interests are related to electromagnetics, information technology and innovative methods in engineering education. His teaching areas cover the analysis and design of electrical circuits and devices, electromagnetic compatibility and information technology. He has published some 275 scholarly works in the above fields including 21 books, monographs and software sets, 77 journal articles and 177 conference papers. He was the leader of some 40 technical and educational research and development projects attracting over AUD1,700,000. He has received numerous national and international awards for excellence in research, teaching, engineering education and community service.