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RATIONALE FOR COLLABORATIVE LEARNING IN FIRST YEAR ENGINEERING MATHEMATICS

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Abstract. Research into tertiary students' first year experience in Australia has focused on the extent to which students adapt to university and their levels of satisfaction, how students adjust to the larger social setting, and issues of transition from school to university, especially approaches to learning. The development of performance indicators has involved the widespread introduction of direct measures of student evaluation of the quality of teaching. Few studies have addressed the relationship between the effectiveness of the learning experience and the broader factors that contribute to student satisfaction or to learning outcomes. The learning of mathematics is often viewed as an isolated, individualistic matter where one sits alone and struggles to understand the material and concepts at hand. This process can often be lonely and frustrating. Small-group collaborative learning can provide an alternative to both traditional whole-class expository instruction and individual instruction systems. This paper will provide a rationale for the integration of collaborative learning into first year engineering mathematics learning and instruction based on a review of international and Australian literature. It is argued that despite an overwhelming acceptance of collaborative learning among researchers and educational organisations, this strategy is not very frequently adopted and used at tertiary level in mathematics. We believe that collaborative learning is an ideal way to help with the transition to engineering mathematics at university from both a social and academic view. It could reduce the large attrition rate in these courses and improve attitudes to engineering teaching and learning.

1. Setting the Stage ...

Considering the strong academic records of most students who choose to do an engineering degree, attrition rates from the course are dramatic. In a study conducted by Astin [1], out of nearly 25,000 students at over 300 institutions in USA, only 43% of the first year engineering students went on to graduate in engineering. A common (but inaccurate) explanation of high student attrition rates from engineering is that most of those who leave lack the academic ability to cope with the rigours of the discipline. In actual fact, studies have shown little difference in academic status between students continuing in engineering and students leaving [3]. A more comprehensive explanation appears to involve a complex set of factors that include students' attitudes toward engineering, their self-confidence levels, and the quality of their interactions with instructors and their peers, along with their aptitude for engineering [1, 3, 7, 15]. Students' attitudes toward engineering and their confidence levels are strongly related to their classroom experiences [15]. Astin [1] showed that compared to majors in other disciplines, engineering majors are

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more dissatisfied with the quality of instruction they receive at university and with their overall university experience, and offers convincing evidence that the prevalent model of instruction in engineering with its extensive reliance on lecturing and individual work plays a major role in the high dissatisfaction level and therefore in student attrition.

Active and collaborative learning techniques can result in higher performance and longer information retention compared to traditional methods. Integrating mathematics, science and engineering courses is an effective means of teaching students to deal successfully with cross disciplinary problems and integrating English into engineering, science and mathematics courses is an effective way to improve the performance of engineering students in oral and written communication [**13**, **16**, **35**]. Research into tertiary students' first year experience in Australia have focused on the extent to which students adapt to university and their levels of satisfaction [**40**], how students adjust to the larger social setting [**27**], and issues of transition from school to university, especially approaches to learning [**34**]. The development of performance indicators has involved the widespread introduction of direct measures of student evaluation of the quality of teaching [**25**]. Few studies have addressed the relationship between the effectiveness of the learning experience and the broader factors that contribute to student satisfaction or to learning outcomes [**26**].

This paper will provide a rationale for the integration of collaborative learning in first year engineering mathematics learning and instruction based on a review of international and Australian literature. This paper forms the basis of a larger qualitative project investigating the effects of group work on engineering students in a large first year undergraduate mathematics subject in both face-to-face and computer supported environments at the University of Technology, Sydney, Australia.

2. Transition from School to University

Tertiary students' first year experiences appear to be crucial to their personal adjustment and academic performance. First year at university for many students entails a considerable time of transition and change, particularly for those entering tertiary education directly after the end of their high school education. The transition from school to university involves adjusting to different learning environments and assessment systems, difference perspectives on discipline-based knowledge and different teaching practices [**32**]. Collaborative learning, where implemented, has been recognised as an effective transition factor in supporting the development of a learning community and by enhancing higher order cognitive abilities [**20**]. Collaborative learning is generally understood to be "learning that takes place in an environment where students in small groups share ideas and work collaboratively to complete academic tasks" ([**10**], p. 362). To collaborate means to share work. This means that whenever possible, learning tasks should be divided up amongst group members so that they share the work equally and help make the project successful.

At the other end of a degree programme, when students are moving to the workforce, there is recognition that traditional forms of university course delivery are often inappropriate in preparing students for the changing workforce [**14**]. Generic skills are becoming increasingly valuable to university graduates and due to the flexibility of careers and the workplace, collaborative learning is a tool that has much to offer both students and educators. The traditional concept of collaborative learning as a group meeting regularly to work together highlights only one type of collaboration between students regarding their learning. Other less intensive activities that can be considered under a broader definition of collaborative learning include seeking assistance from a more senior student, swapping lecture notes, using classroom *free time* to work on subject related matters rather than social discussions, and spontaneous discussion of academic work in social settings [**8**]. Thus, viewed this way, collaborative learning is probably a common experience of many students regardless of any attempts by universities to foster such techniques. Nevertheless, there are ways in which university programmes can increase the likelihood of collaboration and support this type of learning [**8**].

At university, most engineering mathematics classes still consist of instructors talking and writing on the board and students sitting and listening (or not listening). Many instructors are reluctant to move away from the familiar and comfortable teaching methods with which they were taught, especially if they believe that changing methods will require substantial expenditures of time and could hinder their chances for promotion. They will only consider doing so if they are first made aware of the need for change, presented with alternative methods, given convincing evidence of the effectiveness of such alternatives, and assured that adopting such methods does not necessarily require sacrificing syllabus coverage or spending less time on research. A requirement for significant educational reform is therefore the establishment of instructional development for programmes that provide this information and these assurances. An additional necessary condition for reform is for instructors to be convinced that their efforts to improve teaching and learning will not work against their career advancement, and that if successful, the efforts can in fact work in their favour ([**15**], p. 209).

If engineering mathematics instruction is to help students think mathematically, understand the connections among various mathematical facts and procedures, and be able to apply formal mathematical knowledge flexibly and meaningfully, then Davidson ([**11**], p. 53) offers the following motivation for employing collaborative learning methods in mathematics classes:

- Small groups provide a social support mechanism for the learning of mathematics;
- Small group learning offers opportunities for success for all students;
- Mathematics problems are ideally suited for group discussion in that they (usually) have solutions that can be objectively demonstrated;
- Mathematics problems can often be solved by several different approaches. Students in groups can discuss the merits of different proposed solutions and perhaps learn different strategies.
- The field of mathematics is filled with exciting and challenging ideas that merit discussion. One learns by talking, listening, explaining, and thinking with others...
- Mathematics offers many opportunities for creative thinking. Students in groups can often handle challenging situations...

Small-group collaborative learning provides an alternative to both traditional whole-class expository instruction and individual instruction systems. This method of learning can be applied with all major topic areas in tertiary mathematics. According to Neyland ([**28**], p. 35), collaborative learning is one of a range of valuable approaches, based on the premises that:

> each student has an individual thinking style that needs to be identified & used; individual thoughtful concentration & knowledge construction are important components of the learning and problem-solving process; the learning and problem-solving process is enhanced when individuals pool in their ideas, challenge & elaborate on each other's thinking.

3. Constructivism and Collaboration

Collaborative group work is based on the constructivist theory of learning. The basis for collaborative learning arises from the principles presented by von Glasersfeld [**38**] and Vygotsky [**39**]. According to the constructivist theory of learning, people construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences. Emphasis is given to the role of language and communication [**30**]. According to Clements and Battista [**5**], most traditional mathematics instruction has been based on a behaviorist view of teaching and learning. The constructivist view of mathematics teaching is that "...no one can teach mathematics. Effective teachers are those who can stimulate students to learn mathematics" ([**5**], p. 34). Constructivism gives students ownership of what they learn, since learning is based on students' questions and explorations. Language and communication play a critical role in a constructivist learning environment given the social context within which construction takes place [**30**]. Constructivism promotes social and communication skills by creating a classroom environment that emphasises collaboration and exchange of ideas. Students must learn how to articulate their ideas clearly as well as to collaborate on tasks effectively by sharing in group projects. Students must therefore exchange ideas, learn to negotiate with others, and evaluate their contributions in a socially acceptable manner. This is essential to succeed in the real world, since students will always be exposed to a variety of experiences in which they will have to collaborate, cooperate and navigate among the ideas of others.

Sierpinska [**36**] notes the need for effective communication in achieving understanding, the importance of language in communication is described by Pimm [**33**] who views mathematics as a language. Language plays an essential role in the formulation and expression of mathematical ideas. Unfortunately, it is seldom students' expression of their formulation of their ideas ([**33**], p. 202). If mathematics is indeed viewed as a language, then it is clear that students need to practice it and small group learning provides an ideal environment for such practice [**30**]. It is important to note, however, that even if the basis for collaborative learning is constructivism and the important role which language plays in this process are accepted, it is not necessarily true that collaborative learning will always promote effective communication and facilitate understanding. Sierpinska [**36**] cites research into small group discussions by Curcio and Artz to support her claim that "it is now quite clear that neither discussion or writing will automatically lead to better understanding" ([**36**] p. 67). There is also discussion in literature about factors such as off-task behaviour and what Hagelgans [**18**] describe as non-productive ways in which a group can function, all of which are detrimental to effective communication and cognitive development [**30**].

4. State of Research on Collaborative Learning

Interest in collaborative learning has been well founded in research literature. Despite extensive research, many researchers note the narrowness of the focus of such studies and the need for greater research in certain areas. Yackel [**41**] noted that a majority of studies such as reviews of Davidson [**9**] have focused on documenting the effects of collaborative learning on students' mathematical achievement and that more research needs to be done on investigating the processes involved in collaborative learning. Davidson and Knoll [**12**] note that further research is needed to determine the optimal conditions for raising student achievement using various combinations of group rewards and individual accountability. Many researchers also note that most studies are focused at elementary and secondary school levels [**30**] but not much at tertiary level. Norwood [**29**] cites Slavin ([**38**], p. 245) in support of her observation that there is a "paucity of studies examining the effects of collaborative learning at the college level". Slavin ([**38**], p. 52) notes that whilst four literature reviews have found that collaborative learning methods are beneficial at lower levels of schooling, "more research is needed to gauge collaborative learning's effectiveness at senior high and college levels and for instilling higher order concepts".

Despite the increased use of collaborative learning methods at tertiary level, acceptance of such methods has been much slower particularly in mathematics [**30**]. Numerous studies have reported benefits of collaborative learning, most of which stem directly from the opportunity for discussion and interaction that such learning styles provide. Researchers like Gersting and Kuczkowski [?], and Norwood [**29**] add to and support Davidson's [**10, 11**] claims for the advantages of collaborative learning. They observe that mathematics is more fun and that students' interest in mathematics is increased when working in collaborative settings and note the way in which many friendships develop within groups. Gersting and Kuczkowski [?] reinforce the rationale for collaborative learning when they note that the development of academic fellowship is certainly a desirable goal in any tertiary institution. The support and encouragement students can get from working in small groups is in constrast to the feelings of loneliness and isolation which many students encounter in a large lecture room. With regard to particular content areas of mathematics, Brechting and Hirsch [**4**] compared the effects of small group discovery and traditional lecture-discussion in calculus instruction and concluded that the discovery mode was more effective in producing successful achievement in areas of manipulative skills but there were no differences in achievement as measured by a concepts test.

Summarising the research concerning benefits of collaborative learning; academically, collaborative learning stimulates critical thinking and helps students clarify ideas through discussion [**24**]; develops oral communication skills [**42**]; creates an environment of active, involved, exploratory learning [**37**]. Socially, collaborative learning develops social interaction skills [**22**]; creates a stronger social support system [**6**]; fosters a greater ability in students to view situations from others' perspectives [**42**]; fosters team building and a team approach to problem solving while maintaining individual accountability [23]; creates environments where students can practice building leadership skills [2, 21]; psychologically, collaborative learning builds self-esteem in students [24]; enhances student satisfaction with the learning experience [31]; encourages students to seek help and accept tutoring from their peers [19]; significantly reduces test anxiety [22]. Though the research described here is from a variety of contexts, the findings are consistent across disciplines and age groups.

5. Concluding Remarks

There are difficulties with the implementation of collaborative learning methods—resistance from lecturers and students, difficulties with modes of operation, group dynamics, and organisational issues. However, the case for investigation and trial of this teaching and learning method in university mathematics, particularly for groups such as engineering students, is strong.

The literature presented here demonstrates that there is overwhelming acceptance of collaborative learning among researchers and educational organisations, however this strategy has not been very frequently used at tertiary level in mathematics. Implementing collaborative learning is a complex process. Much of the research on collaborative learning has proposed that the benefits are usually long term rather than having an instant effect. Examination marks may not increase but using properly structured group work early in a degree course can help the students to reflect more on their work. Changes in teaching and learning styles are not a quick and easy matter. Change is a process that involves both trying out new strategies and techniques as well as carefully considering the goals for which those practices are intended. The key is to provide instructional development that informs instructors about alternatives to traditional teaching and assessment method—what they are, what the evidence is for their effectiveness, and how they can be implemented without taking excessive preparation time or having to sacrifice important course content. The time demands imposed by the adoption of student-centered instructional approaches like active, collaborative, and problem-based learning can be minimal as long as new methods are introduced starting with techniques that do not require much preparation or class time. Another concern that makes instructors reluctant to move to more student-centered instructional approaches is the fear of student dislike of these methods. Instructors should explain to students what they plan on doing and their reasons for doing it. Instructors should also avoid rigidity in the application of such methods, recognising that some students have unique time constraints and other problems that should be dealt with on an individual basis. It is only by increasing the use of such approaches that student resistance will be minimised.

Collaborative learning has a positive effect in the cognitive domain as well as the social and affective domain at all levels in mathematics. We believe that collaborative learning is an ideal way to help with the transition to engineering mathematics at university from both a social and academic view. It could reduce the large attrition rate in these courses and improve attitudes to engineering teaching and learning.

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