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Assessment Strategy for an Engineering Problem-solving Course*

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The operational aspects of an assessment strategy for an Engineering Problem-Based Learning (PBL) course initially involved an audit of existing and varied student skills and competence to facilitate their effective deployment into well-balanced teams. This balance encourages effective mentoring within and between teams. The strategy included summative and formative assessment, the former being tailored to individual students' existing skill levels. Throughout, the emphasis is on advancement of skills and competence rather than simply achieving a minimum standard. The strategy provides the flexibility for equitable assessment of students with different initial skills and competency, which proves particularly relevant to students studying in the distance mode who may have considerable professional experience and advanced skills and competence in some areas. By tracking progress, students develop an individual portfolio of achievements that can be continued throughout their study programmes and professional lives.

Keywords: problem-based learning; engineering education

BACKGROUND

SINCE 1967, when it started, the University of Southern Queensland (USQ) has developed an international reputation for offering high quality academic programmes in the on-campus (internal), off-campus (distance) and online delivery modes. It shows in winning the Australian Good Universities Guide University of the Year Award 2000–2001, winning the Commonwealth of Learning Award of Excellence for Institutional Achievement at the third Pan-Commonwealth Forum on Open Learning in Dunedin, New Zealand in July 2004, and being chosen as the inaugural winner of the 1999 International Prize for Excellence in On and Off Campus Leadership and Innovation by the International Council for Open and Distance Learning. In October 2005, the USQ problem-based learning (PBL) academic team won the Australasian Association for Engineering Education Award for Excellence in Engineering Education for curriculum development in the PBL courses, was chosen as a 2005 finalist in the Australian Award for University Teaching, and won a Citation for Outstanding Contributions to Student Learning in the 2006 Carrick Australian Awards for University Teaching.

The university operates several satellite campuses throughout the world, with the principal one at Toowoomba, approximately 130 kilometres west of Brisbane, Australia. The Faculty of Engineering and Surveying (FoES) is one of five faculties at the university.

In recent years, the technical ability of engineering graduates in general has been questioned, with most of the criticisms relating to a lack of skill and competence in core areas of basic mathematics and science, and issues such as retention of knowledge and inability to transfer basic knowledge to real-life engineering scenarios [1]. As well as technical competence, it is also important for engineering graduates to acquire a range of generic, or transferable, skills that will allow them to operate effectively in a future professional environment. Unfortunately, it has been recognised that engineering education does not completely address gaps in critical generic skills [2]. Deficiencies have been identified in the ability to work in multi-disciplinary teams, in the ability to work in a global virtual environment, in digital communication skills [3]; in ability to adapt to change and solve problems in unusual situations, in ability to think critically and creatively and in a commitment to continuous lifelong learning and self-improvement [4].

FoES recognised that educational approaches were required that would address these deficiencies and provide engineering graduates with the enhanced skill and competence necessary to carry out their professional responsibilities in today's virtual global environment. The use of PBL provided a mechanism to do this and demonstrate that participants had developed the necessary professional skills required by the surveying and engineering professional accreditation bodies [5, 6]. It was also an opportunity to establish an innovative teaching practice in engineering education at USQ that was outside the dominant transmission model normally used in universities [7], and that recognised that learning may be more effective when undertaken in groups [8].

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Consequently, in 2001, FoES introduced a problem-based learning (PBL) approach for several courses to ensure that graduates developed problem-solving skills and the ability to work effectively in multidisciplinary teams. This was consistent with the university's vision that graduates be well advanced in discipline expertise, professional practice, global citizenship, scholarship and lifelong learning. The PBL approach was also consistent with the faculty's philosophy that engineers and surveyors (spatial scientists), being predominantly problem solvers, must be able to use the latest technology to find creative solutions to multidisciplinary problems throughout their professional lives. It was considered that PBL would be a preferred strategy to achieve this since it purposefully creates situations from which motivated learners should not be able to escape without broadening their perspectives and acquiring new skills [9].

Students learn to work together in multidisciplinary teams to solve problems by collaboration [10] using a system similar to the interdisciplinary PBL platform described by Acar [11]. Rather than project-led education (PLE) or project-organised learning (POL), which involves projects supported by theory-based lecture courses [12] and usually focuses on team-based activity relating to large-scale open-ended problems [13], at USQ teams are given a number of smaller-scale open-ended problems to solve; hence the strategy is truly PBL.

The PBL strand consists of a series of four consecutive courses, with an additional final year research project seen as the capstone. The main objectives of the first two PBL courses, which are compulsory for all students in the faculty, are to develop the fundamental skills needed for participating effectively in multidisciplinary teams and to expose students to a wide range of problem-solving tools. Subsequent problem-solving courses are designed to expand and improve these skills, and to impart fundamental technical content in several discipline areas.

STUDENT DIVERSITY

At USQ students may elect to study in the on-campus (internal) or off-campus (distance) modes. Distance students study from various geographic locations around the world, which enriches the learning experience with cultural diversity, but also creates its own set of logistical problems. These are further complicated in the problem-solving courses by the fact that students in the same team may be studying at Associate Degree (two year), Bachelor of Technology (three year), Bachelor (four year), or Double Degree (five year) levels. Students enrolled in the PBL courses may also be studying different majors offered in the faculty: Agricultural, Civil and Environmental Engineering; Electrical Engineering, Electronic and Computer Engineering; Mechanical and Mechatronic Engineering; Surveying and Land Information. Because of different disciplines, different study modes, and different programmes, existing knowledge, expectations, level of interest and other cultural and personal differences, the difference in learning objectives of each individual student can be profound, and this can complicate the assessment process. It is interesting to note that most of these elements have been identified by others as core principles that need to be considered when designing education for adult learners [14].

Most students studying in distance mode do so because they are already employed in some capacity in industry. Because they are already in the workforce, many have different skill levels and personal competency attributes compared to internal students, and their '*learner context*' [15, 16] will be quite different. There is also a possibility of high school leavers not yet possessing the skill set to truly be independent learners. It is clear that during the setting of objectives and assessments there needs to be some recognition of prior learning or skill, particularly for those students who have already developed significant skills through experience in the work force. And this must be done in an equitable manner so as not to advantage or disadvantaging any group or individual. It seems logical that, to do this effectively, the learning objectives and assessments should be, at least partly, individualised for each student.

It is also recognised that peer-assisted learning (mentoring within teams), which can have a motivating effect on the teams [10], and mentoring between teams, must be encouraged and rewarded. Gibbings and Brodie [17] reported the development of an assessment strategy for the first of the PBL courses offered in FoES at USQ to overcome identified shortcomings, and to effectively assess achievement and advancement of skills and competence, in a way that recognises diversity and prior skill and learning, and that does this in an equitable manner.

ASSESSMENT—STRATEGIC ASPECTS

Students enrolled in ENG1101 are placed in teams of up to eight members. Each team is allocated a staff member to act as a facilitator whose role is explained by Gibbings and Morgan [18, 19]. The facilitator is also responsible for assessing his/her teams, although others have cautioned against this since there can be a conflict in roles in being a judge and facilitator at the same time [12]. To help alleviate this conflict, an examiner is appointed who has overall responsibility for administration and assessment of the course, and staff training and coordination. Consistency of assessment between facilitators is achieved by staff training and documentation of requirements in a course facilitator's guide [18]. The examiner performs a moderation role to further promote consistency between facilitators and to ensure that

due diligence has been applied to the assessment process.

A search of the literature reveals a plethora of assessment methods employed in engineering education today. It is commonly agreed that the assessment methods should be compatible with the learning objectives and consistent with the general course pedagogy. With respect to PBL this means assessment to establish the individual's knowledge, skill and competence rather than testing for factual knowledge [20].

While the effort to improve engineering graduates' skills and competence in areas that have been identified as deficient [3, 4] are admirable, many engineering programmes encounter difficulties with assessment of these attributes, particularly portfolio assessment [21]. Though the traditional written assessment still appears to be the dominant method of assessing students in engineering courses, it is of questionable validity as a means of assessing students' ability to apply technical skills and knowledge to real-life situations, and even less valid for assessing the real-world skills or 'soft skills' [22], mentioned earlier, that engineering graduates are expected to perform in their professional work [23]. For PBL assessment to be authentic it must embody a range of non-traditional assessment techniques. It must also be an integral part of the actual course work; a philosophy that applies to any course that employs a constructivist paradigm [23], as ENG1101 does, if the assessment is to be consistent with the pedagogy.

A frequent criticism of the assessment of team projects is that individual students in the teams often receive the same group mark irrespective of their contributions [23]. Peer assessment has been successfully used in the past as a means of discriminating individual performance within groups by multiplying the team mark by an individual multiplier [23]. The individual multiplier is arrived at by peer evaluation of the individuals' contribution to the team's performance [23]. Reflective reports or portfolios have also been used to encourage students to reflect on their learning and the group's processes [23].

In accordance with the recommendation of Frank and Barzilai [10] and others [for example, 23], the assessment strategy in ENG1101 is entirely in accordance with the 'constructivist paradigm' [15, 24], and the 'collaborative learning' paradigm [9, 25]. The assessments are also used as an incentive to encourage desirable behaviour, such as mentoring within the teams and mentoring between teams, and to discourage undesirable activity. In accordance with this philosophy, Gibbings and Brodie [17] reported on a strategy to update the assessment scheme in the first PBL course to account for the following:

- Some students in teams may want to do all of the work themselves and not share the workload with other team members. This may occur for several reasons, the most common is that the 'high achievers' don't want to rely on others to carry out tasks that could ultimately affect their own 'marks'.
- Some students may not want to participate at all, or contribute very little to the team effort. The assessment strategy ensures that the individual only, and not the team, is disadvantaged in this case. Note that contributing little or nothing to the team's project, and then trying to claim a disproportionate contribution and share of the project mark, falls into the broad definition of plagiarism [26] and cannot be tolerated.
- Incentive is provided for students to learn new skills. For example, under the earlier assessment system, those who were proficient at a particular skill (for example, report writing) would tend to adopt that role in all projects because that gives the team its best chance of receiving a 'good mark' for the projects.
- Real incentive is provided to encourage mentoring within the teams. Assessment also requires that teams provide evidence of such mentoring—if it is important, and students need to learn it, and it is in accordance with learning goals, then it should be assessed [27, 28].
- Incentive is provided to individuals to encourage the appraisal of other teams' proposals (mentoring between teams) and to provide appropriate feedback to these teams. Evidence must also be provided by teams of what action was taken as a result of this feedback. This mentoring and feedback by peers, or 'trial and error', is considered by Savin-Baden [15] and Acar [11] to be an important part of learning, and is also considered to be a strong motivator for the teams involved [10]. However, to be effective, students are made aware that this feedback is not used as a differentiation tool for formal assessment. In fact, all assessment criteria, both formative and summative as recommended by Acar [11], are clearly communicated to students to ensure the assessment strategy has the desired effect [15].
- Personal reflection by the individual is encouraged, and direction is provided to students on the requirements of an individual portfolio of reflections. The assessment scheme was changed to place less emphasis on the team mark for the projects and on the project solution, and more emphasis on what the individual has learned, and how and why the individuals' skill and competence levels have increased.

In ENG1101 students had in the past been assessed on team projects with the project marks being modified to an individual mark based on peer and self-assessment reports [29]. Some weaknesses of this approach were noted and these were largely due to not providing appropriate incentive, through assessment, for the types of behaviour that were considered desirable such as collaborative learning and mentoring. Others such as Savin-Baden [15] have also recognised that assessment

could undermine collaborative learning and the team process that is necessary in PBL.

The revised assessment strategy described by Gibbings and Brodie [17] places the emphasis on advancement of skills, and learning new skills, rather than just achieving a minimum standard. This was achieved by each student individually negotiating, and being assessed on [as suggested by 30], objectives, goals and targets for each project within the PBL course. The direction was therefore determined by the learner within the constraints of the problem to be solved, which is seen as desirable for adult learning [24].

This approach recognises that not all students will have the same learning objectives, nor will they be faced with the same issues (particularly considering the student diversity mentioned earlier), so it is necessary to be flexible [31]. It also recognises that true 'engagement' can come from students negotiating their own learning objectives and constructing them within their own context. This should lead to a sense of 'ownership' and enhanced motivation [31].

This assessment strategy provides students with guidance and encouragement to:

- take responsibility for their own learning: this is generally referred to as 'constructive alignment' [32, 33], or 'constructivism' [24];
- identify their own individual learning objectives that allow them to extend and build on existing skill and competence;
- develop suitable strategies to achieve these individual learning objectives;
- provide a mechanism for students to monitor their own progress throughout the strand of PBL courses.

TEAM SELECTION

Initial Skills Audit

The assessment method reported by Gibbings and Brodie [17] involves the initial auditing of existing skills and competencies of each student and continual skill assessment to map student's progress throughout the full suite of PBL courses. The skill assessment is used to allocate students with different levels of skill in various fields into well balanced teams, which in turn encourages mentoring within the teams.

Questions are written in easy to understand language, worded to overcome potential problems with cultural diversity and expressed in terms of how well students believe they can perform certain defined activities. These initial skill audit questions are also linked to the course objectives wherever possible. For example, part of a course objective is: 'Communicate information in a professional manner'. A related task that describes one of the skills that students are expected to achieve is: 'Prepare a professionally written technical report in English on a word processor'. The corresponding questions that appear in the initial skill audit are:

1. How would you rate your ability to use a word processor?
2. How would you rate your English expression, grammar and spelling?
3. How familiar are you with standard referencing styles?

Students grade their performance of each of these activities by checking a box against a 5-point scale where 1 denotes little or no knowledge, and 5 denotes experienced and expert in all aspects.

At this stage there is a possibility that some students may either underestimate or overestimate their skill levels. Consequently students are advised that:

- the audit is not part of any formal assessment;
- if students underestimate skills in a particular area, they may be placed in a team with someone else, who is supposedly strong in this same area, who may be charged with the responsibility of mentoring them in this skill. This will be ineffective and inefficient for both parties, and their team will be disadvantaged due to not having well balanced skills;
- if they overestimate skills, then they may be asked to mentor another team member in this skill area. In this case mentoring won't be effective and they and the team will consequently be penalised.

ASSESSMENT—OPERATIONAL ASPECTS

Assessment Scheme Overview

The assessment scheme involves both individual and team assessment, and a mix of summative and formative assessments. Figure 1 shows how these assessments are linked and how each element contributes to student's individual marks.

The assessment scheme involves five main sections that contribute to the student's individual mark:

- communications log;
- team submission of project reports;
- peer assessment of contribution within the team;
- individual contributions;
- individual portfolio of set-work and individual reflection on learning.

Communications log

Management of the course is largely through use of the WebCT Vista ©™ e-learning system. This platform provides access to web-based material, online quizzes and surveys, and communication facilities such as electronic mail, discussion boards and synchronous chat sessions. Students are required to use the discussion boards for most of their communications within groups for the first few weeks, after which time they may negotiate within their teams for other alternative commun-

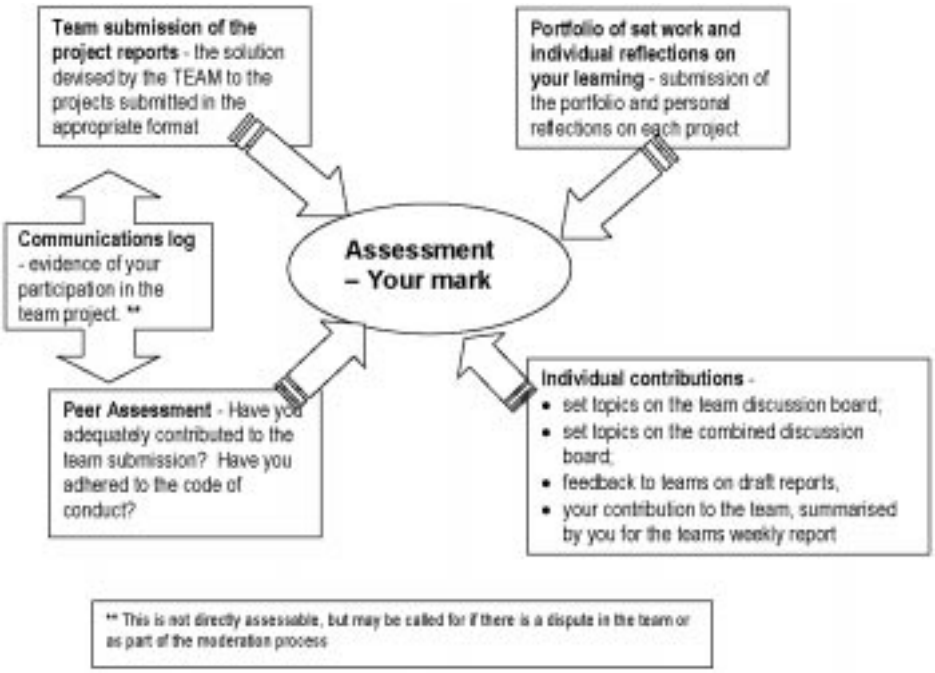

Fig. 1. Overview of assessment scheme.

ication methods if they prefer. Each team has their own discussion board, which only they and the course administration staff can access. In addition, groups of four or more teams are also given access to a combined discussion board to facilitate between-team communications.

Students' contributions to both team and combined discussion boards are assessed. It should be noted though, not all contributions to the discussion boards form part of the summative assessment. Threads, messages and replies are managed and assessed by facilitators having access to (and contributing to) these discussion boards on WebCT. This provides an ideal mechanism for facilitators to monitor individual and team progress.

Team project reports

Before the first project is released, students are required to undertake an online quiz dealing with fundamental technical concepts. This is used to focus attention on the technical skills and competencies that should be gained from the projects. This assists students to identify their own personal learning goals for the project, and provides a base for comparison to determine to what extent their learning goals were achieved.

Students are required to negotiate suitable roles within their team for each project. This is in accordance with research that suggests that adult learners want control over learning based on personal goals, and that learning will increase as a result [14]. There is convincing evidence that those who take some initiative and become involved with their own learning in this way, will learn more than those who take a more passive approach [34].

Each team is required to prepare a plan that includes each individual's role and responsibility within the team, and their learning objectives. This approach recognises that not all students have the same learning objectives, nor are they faced with the same issues (particularly considering the student diversity mentioned earlier), so it is necessary to be flexible [31]. It also recognises that true 'engagement' can come from students negotiating their own learning objectives and constructing them within their own context. This may also lead to a sense of 'ownership' and enhanced motivation [31].

Teams are required to publish preliminary project reports to the combined discussion board by a designated date. Assessment marks are awarded for work done to date, and members from other teams and facilitators have the opportunity to provide feedback on what has been submitted. Individuals are given formal credit for this activity as part of the summative assessment strategy.

All team project reports are assessed by their facilitators using the same marking rubric. Constructive feedback is again provided to the teams at this time. Consistency of assessment between facilitators is achieved by staff training and documentation of requirements in a course facilitator's guide [18]. The examiner performs a moderation role to further promote consistency between facilitators and to ensure due diligence has been applied to crediting individual skills and competence.

Teams then have the opportunity to alter their submissions in light of the feedback and resubmit the final project report to a course assignment drop

box in WebCT. This final submission is again formally assessed, and must provide evidence of changes or actions taken subsequent to the feedback outlining how and why the initial report was improved as a result. This reflection, opportunity to respond to feedback (and to carry out informal assessment of other's work by providing feedback), and collaboration within the team, are seen as critical to the learning process [35]. In this way, the assessment becomes an integral part of the learning process, and should encourage students to engage in the learning tasks associated with the problem solution, which is one of the most fundamental tasks of education [36].

Peer assessment of contribution within the team

One of the first tasks required of the teams is that they negotiate, agree and document a team 'code of conduct'. This sets out roles and responsibilities for all members of the team and includes what is expected of the facilitator. Amongst other 'rules', penalties will be detailed for non-participation, or less than acceptable contributions, by individuals.

At the completion of each project the teams are required to agree and report on the contributions of individuals within the team. This is normally expressed as a percentage of the team mark that each individual should receive. Of course there is an appeal mechanism for individuals who feel the team has not allocated them what they consider an appropriate percentage, but experience has shown that this is very rare, mainly because the 'rules' were agreed by the team at the beginning and all individual team members know exactly what to expect. The team mark for each project is multiplied by the stated individual percentage to arrive at an individual mark for each team member.

Individual contributions

The individual contributions comprise two separate parts:

- submissions and contributions to the team efforts;
- submissions and contributions to individual tasks.

Contributions to the team effort are evidenced by postings to the discussion board and include:

- contributions to the team weekly reports (posted to team discussion board);
- contributions to initial activities such as team code of conduct, team communication strategy, project key concepts, timelines (posted to team discussion board);
- feedback to other teams on their project draft reports (posted to combined discussion board).

Individual tasks that don't affect the team include:

- participating in an initial project online assessment to focus attention on technical skills (discussed in the 'team project' section of this paper);
- postings in response to selected topics for discussion (only some contribute to summative assessment), for example, teamwork, team dynamics, leadership, conflict resolution, etc. (both team and combined discussion boards);
- individual portfolio (detailed in the 'individual portfolio' section of this paper).

Individual portfolio

Students in ENG1101 are required to maintain a portfolio of set work and individual reflections on their learning within the course. Portfolios have been recognised by many engineering accreditation bodies around the world as offering an acceptable measure of student attainment of graduate attributes [37–38]. Individual portfolio assessment in ENG1101 depends more on the process, reflection and self-evaluation rather than on specific quantitative criteria [24]. And the emphasis is on advancement of skills, and learning new skills, rather than simply achieving a minimum standard. This is achieved by each student individually negotiating, and being assessed on, objectives, goals and targets for each project within the PBL courses. The direction is determined by the learner within the constraints of the problem to be solved, which is seen as desirable for adult learning [24].

To assist students with this task, a comprehensive list of learning objectives (normally written as tasks that can be performed) is provided and each of these is linked to one or more course objectives. These are presented in a spreadsheet and students are encouraged to use this as the beginning of what will become a portfolio of skill and competence.

For example, one course objective is 'Identify, analyse, discuss and apply elements of teamwork that affect team success'. The corresponding learning objectives for students to choose include:

- Identify necessary leadership qualities.
- Effectively lead a team.
- Analyse the dynamics of a team.
- Effectively negotiate with others within and outside a team.
- Seek and evaluate contributions of other team members.
- Utilise prior knowledge and experience of team members from diverse cultural and technical backgrounds.
- Establish and document roles and responsibilities within a team.

Students are encouraged to add their own objectives to supplement those provided.

Teams are required to submit a plan, similar to the system noted in Isaacs [35] for the project, incorporating each team member's individual learning objectives, and these must all be agreed by peers within the team. A constraint is that these individual learning objectives must be consistent with course objectives (and graduate attributes) and be aligned to areas in which the student requires improvement (rather than an area of existing high level skill and competence). This

encourages the development of new skills since the students are assessed on these—teams whose plans demonstrate the development of new skills by its members will potentially receive higher marks. By tracking progress in the achievement of objectives, the students can maintain an individual portfolio of achievements throughout the suite of PBL courses, and potentially through to, and even past, graduation, as is recommended by recent literature [21, 39]. Because this improvement by individuals and the team collectively is formally assessed, mentoring within the teams is encouraged.

Each student's final reflection on the projects includes a personal assessment of the level of achievement in these skills. This is submitted with the individual reflections in the final project report and also forms part of the student's individual portfolio. They are able to judge how well they have performed in these areas after receiving feedback on their preliminary team reports. As this process is carried out after each project, students can monitor their progress in each of these skills throughout the course.

ANALYSIS OF ASSESSMENT SCHEME

This strategy for formal assessment of objectives provides documentary evidence that each student has achieved the minimum standard expected of a graduate as dictated by PBL course objectives, programme attributes, accreditation bodies, professional associations and defined graduate attributes. Stakeholders can only be given an assurance that the required graduate attributes have been attained if there is some evidence to point to their development by the graduates [40].

The assessment approach, involving tailoring to individual students' existing skill and competence levels, also provides the flexibility for equitable assessment of students with skill levels that are already well above the required minimum standard. Students who may have highly developed skills in some areas, as is often the case with distance students who are already in the workforce, can now be assessed on an equitable basis with students who may not have the same starting level of skill.

In essence, students develop an individual log to record their progress in skill and competence achievement. This approach is similar to what has been adopted by several professional associations in Australia that have the responsibility, often under legislation, of assessing individual members against national competency standards before granting professional registration. It has also been successfully used in various forms in education, for example, Albert and Morrison [41] and Harley [42], although it does not appear to be common in engineering or technical education. The log or portfolio provides a structured record, in condensed but specific form, of the student's progress in the development of skills and competence.

The skills and competencies assessed in the portfolio are directly linked to course objectives and therefore graduate attributes. This portfolio of skills is essentially a professional development audit and provides a status report of the students' progress at any particular time.

The skills portfolio demonstrates, and formally records, the practical realisation and advancement of skills and competencies. Evidence of achievement of skills and competence is presented and assessed in the student's own portfolio. Although this is essentially self-assessed, there are several ways that students can demonstrate the achievement of a particular skill level:

- Peer assessment/agreement and documentation of performance during the conduct of the team projects (usually in accordance with the peer agreed team roles and predetermined individual learning objectives).
- Evidence of effective mentoring of others within the team in these skills.
- Individual requests supported with documentary evidence of conduct during the project (this may be used by students who enrol in programmes with advanced standing).

This process records and tracks the student's achievement of skills and competencies in the identified skill areas. This process allows facilitators to recognise existing areas of specialisation but still provide documentary evidence of the achievement of skills and competencies. It also allows the examiner to identify areas of specialisation where a student has achieved higher than minimum levels of skills, knowledge and competency, since the process provides a mechanism whereby achievement above the minimum required can be recognised, assessed and credited. This encourages students to attain skills and competencies in excess of the mandatory requirements for graduation.

The formal assessment strategy also encourages students to develop new skills in areas where they have previously identified a weakness. The opportunity for feedback and mentoring within and between teams is enhanced. Formal credit is given to individuals for providing feedback to other team's work. Both inter-team and intra-team mentoring is assessed in the individual portfolios. It is believed that this increased mentoring will have the added advantage of encouraging better intra-team communication and should therefore foster better teamwork.

CONCLUSION

The strategy of an initial skill and competency audit for students offers several major benefits. It allows the tailoring of assessment to individual needs and caters for prior learning and existing skills. This enables more effective use of student

diversity and encourages mentoring within the teams.

This strategy provides a mechanism to allocate individual assessment marks from team projects. The summative assessment provides the flexibility to assess, on an equitable basis, the attainment of skills and competencies at a higher level than the minimum requirements because it rewards an increase in skill levels and development of new skills, rather than assessment against some predetermined minimum criteria. This encourages students to direct study and energy into areas which will most benefit their future and professional careers.

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