Teaching Project Management using a Real-World Group Project

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***Abstract*—It is well established that an effective pedagogy for project management requires students to get real-world experience. The challenge in providing this when teaching undergraduate engineers is the dichotomy between achieving realism and maintaining sufficient simplicity to make the course tractable. A real-world group technology project at Victoria University of Wellington (VUW) in New Zealand establishes essential non-technical attributes required by the engineering profession while covering key elements of the project management body of knowledge (PMBOK). This paper first shows how the project covers the knowledge required in project management and then presents the results of two years of data collected from students' reflection on their own learning. We have established a pleasing congruence across the years against the specific learning topics of team working skills, communication skills and personal working skills with an improvement in project management skills. A key finding emerging from our analysis is the importance of reinforcement learning and reflective learning. We show a key link between these two learning mechanisms and the project pedagogy. Further analysis shows the link between the project pedagogy and four skill areas acquired. Finally, our research has identified specific areas for us to focus on for subsequent years.**

Keywords—project management, real-world project, graduate attributes

I. Introduction

It is not sufficient to equip engineering undergraduate students with just a technical education. The professional requirements for accreditation of engineering education in New Zealand [1] define more non-technical attributes for graduates than technical attributes. One of the ways Victoria University of Wellington (VUW) addresses non-technical attributes is through a practical application of project management to an environmental technology programme using group work.

Addressing non-technical attributes through project management starts with defining a practical scope and making it relevant to students focused on demonstrating technical prowess. There are several obstacles: project management is met with scepticism from non-practitioners, there is only a vague consensus over what it should be and there is no single model [2]. This is despite, or maybe because, established approaches such as PMBOK [3] and PRINCE2 [4] (the acronym for PRojects IN Controlled Environments, which is a de facto process-based method for effective project management), and modern methods such as SCRUM [5] have been applied to impose conformity and control on their practitioners in the name of professionalism [2][6]. Far from there being consensus, project management models are diverse, with as many as 1,000 in publication [7].

In New Zealand skepticism about formalising approaches resonates with the local culture of using a basic approach and "she'll be right". But "she isn't right" and out-of-control projects continue to reap disaster with as many as one in six organisational change technology projects having 200% cost overruns [8]. Just recently two NZ government IT projects blew out from $33m to $163m [9] and from $71m to "in the range of" $155m [10] respectively.

Another key challenge is learning and teaching: how to ensure real learning that makes a difference to students' engineering attributes. It is well established that it is not sufficient merely to 'teach' project management [11]; group work [12] and realistic project contexts [13] are essential to learning. Using a group project to achieve non-technical outcomes has to be simple enough to fit within the undergraduate teaching programme yet realistic enough to ensure students acquire skills for employment.

To solve these challenges, at VUW we follow up in-class teaching with a practical project that gives students responsibility for real-world outcomes to develop their learning of non-technical skills. We have found this to be a good pedagogy for grounding the project management teaching, establishing its relevance to the students and enabling them to learn essential non-technical engineering attributes. However, this is not the only approach available, as we discuss next.

II. Pedagogical Alternatives

There are a number of pedagogies available for project management. Professional project management development and certification through Project Management Institute (PMI) and PRINCE2 are predominantly based on training courses. These are available from around 2,000 providers worldwide [14][15]. While direct teaching is an important component of learning, it should be supplemented with other teaching methods, such as modelling, simulations, case studies and group projects. How does the use of a real-world group project compare to these?

Using real-world projects to teach construction project management is simply not practical: realism requires a scale that is too large and it takes too long for students to understand

and apply the method [13]. To overcome this, Stanford University uses software modelling tools to enable students to create construction plans that have sufficient detail and completeness to learn important project management concepts first-hand [13]. Important lessons learned include: time-based quantities, intuition for workflow, project monitoring (by plan features) and project fundamentals (also by plan features). Even so, direct experience stops at planning, so lessons to be learned in project execution are at best left to inference from the plan.

Simulations extend the software model into the project execution phase and become tractable as a learning tool in software engineering project management. The University of Stuttgart has developed a software engineering simulation tool used by nine Universities in Austria, Germany and Slovakia to supplement classroom teaching of project management [16]. This enables students to create software development projects and to execute them by simulation, gaining feedback and having the opportunity to change decisions to improve results. A system dynamics tool used at the University of Reading used simulation in an experiment to confirm that students gained better understanding of typical behaviour patterns of software engineering projects and raised their interest in project management [17].

The key limitation of simulations is that they lack real people, having neither a real client with real outcomes nor a real development team. Simulations can have other limitations, e.g. in supporting agile lifecycles or only modelling basic principles. This illustrates that significant investment is needed to get realism from software tools be it models or simulations.

A third alternative used in universities is case studies, through documentation, class discussions and/or by inviting in guest speakers with first-hand knowledge [12][18][19]. These go beyond simple classroom exercises and anecdotes from the lecturer's experience, to use real-world scenarios that students analyse to undertake assignments that they can evaluate from actual outcomes. While this presents more realism, key limitations are that students are learning second-hand and have little opportunity to ground their learning with direct experience. This limits case studies as a means to acquire practical skills [11].

A group project addresses some of the limitations of using modelling, simulation and case studies by enabling students to get first-hand experience of managing a project. This can be combined into an integrated approach, where more mature students manage group projects that teach technical skills [20]. However, it is not a given that group projects address the scope of learning required or provide real-world experience.

III. Learning Requirements for a Real-world Project

To understand how a real-world project can enable undergraduates to acquire the non-technical attributes specified by the engineering profession, we must first ask what attributes are required, how should they be learned and what scope of project management should be covered?

The seven non-technical graduate attributes defined by the Institution of Professional Engineers New Zealand (IPENZ) [1] are based on international accord and are itemized in the following list. The VUW project has elements of all of these, which are all part of applying technical skills in professional practice:

1. Assess health, safety, legal and cultural issues of the engineer and society
2. Evaluate the impact of engineering on sustainability and the environment
3. Apply ethical principles to engineering practice
4. Function effectively as an individual and in a team
5. Communicate effectively on complex engineering activities
6. Apply management principles and economic decision making to manage projects
7. Prepare to engage in life-long learning.

The scope of project management as defined by PMBOK [3] includes knowledge areas itemized in the following list. The VUW project has elements of all these areas:

1. Organizational influences: the project environment
2. Project life cycle and processes
3. Management of project:
    a. Integration
    b. Scope
    c. Time
    d. Cost
    e. Quality
    f. Human resources
    g. Communications
    h. Risks
    i. Procurement
    j. Stakeholders.

Previous research by Ojiako *et al.* [21] identified the project management pedagogy 'dimensions' important to engineering students. These were in-class learning, out-of-class learning (provided through another course at VUW) and acquisition of generic skills (supporting the IPENZ requirements for these).

In another paper [22], the authors identify the key generic or transferable skills as the following:

1. Development of inter-personal skills
2. Experience of self-management
3. Development of critical thinking
4. Development of communication skills with others.

In the next section we show how our real-world project at VUW brings all these threads together to give engineering students a first-hand learning experience in these areas.

IV. The VUW RiverWatch Programme

Engineering at VUW comprises three majors: electronic and computer system engineering, network engineering and software engineering. In their third year, undergraduate students take two courses in project management, the first being a taught theory course using lectures, in-class discussions and group work, and the second being practical application of the theory through participation in the RiverWatch programme.

RiverWatch is a multi-year, multi-project programme to develop a technology platform for a voluntary organization called WaiNZ [23] that enables the New Zealand public to become "kaitaki" (Maori term for guardians) of their rivers and streams. Students have developed a website, smartphone applications, unmanned aerial vehicles (UAVs) and water quality data sensors for this purpose. Each year students form teams of five to broaden the base and push the boundaries of the platform with new development projects. The 2014 cohort's key highlights included developing new iOS, Android and Windows phone apps, prototype water quality measurement devices, a UAV relay network to extend monitoring range and website enhancements. The programme has run for three years.

Students learn professional skills directly through their project work via the following mechanisms:

1. Creating self-organizing project teams [24]
2. Selecting and elaborating client requirements
3. Preparing project initiation documents, covering: requirements, business case, work breakdown structure (WBS) & Gantt chart, risk management, quality plan and communications plan
4. Communicating with the client weekly
5. Maintaining working documents, including team meeting minutes, updated Gantt chart and risk register
6. Presenting team achievement to the client
7. Demonstrating the team product to the client.

As a result of feedback appraisal from 2013, the two project management courses were adjusted to improve learning:

- The RiverWatch programme was introduced during the theory course to improve familiarity with it and the students produced an outline initiation document for the programme as part of that course
- The time available for students to do project initiation at the start of their RiverWatch project was extended by one week in the practical course to reduce risk
- Practical approaches to undertaking risk management were taught in the theory course and applied to the RiverWatch programme
- Communication with project stakeholders was introduced for the first time in the theory course to extend the students' learning of communication skills
- Writing an individual reflective report.

The RiverWatch project addresses the IPENZ graduate attributes through the direct student experiences shown in Table 1 and addresses the PMBOK knowledge areas as shown in Table 2. The generic or transferable skills identified in the previous section are addressed as shown in Table 3.

The next section presents how we evaluated these learning experiences.

TABLE I. HOW RIVERWATCH ADDRESSES IPENZ GRADUATE ATTRIBUTES

IPENZ Graduate Attribute (3. and 7. Excluded)	**RiverWatch Learning Experience**
1. Assess health, safety, legal and cultural issues of the engineer and society	1. Comply with VUW laboratory and offsite health and safety requirements during their project 2. Identify project risks as a team and manage them through team meetings 3. Achieve community cultural outcomes with technology products to meet WaiNZ goals
2. Evaluate the impact of engineering on sustainability and the environment	4. Apply technology to enable WaiNZ and the public to improve the sustainability of beef and dairy farming and to protect the river environment in NZ 5. Define the environmental context in the product demonstration and answer client questions
3. Apply ethical principles to engineering practice	4. Apply ethics to client commitments, working together as a team and University requirements
4. Function effectively as an individual and in a team	6. Deliver an individual contribution to a group project with individual accountability to the team and to achieve personal assessment marks 7. Learn about team dynamics, leadership and motivation through teamwork and inter-project collaboration, by making real-world project decisions that result in a usable end product
5. Communicate effectively on complex engineering activities	8. Learn to write specifications and plans the project team can use effectively 9. Take turns to provide a verbal achievement report to the client weekly and get a real-world response back 10. Communicate effectively with the business owner (course lecturer) by producing project and technical documentation in writing and get feedback through assessment 11. Present achievement to the client and business owner in a formal team presentation and answer real-world questions 12. Demonstrate tangible end products to the client and answer real-world questions 13. Submit apps to the app stores for publication 14. Write a reflective end of project report to capture learning from the project experience and receive assessment and feedback
6. Apply management principles and economic decision making to manage projects	15. Work to a project brief the team has created and had reviewed 16. Choose an appropriate project lifecycle and plans and execute them, monitoring actual achievement against real deadlines 17. Produce an outline business case including project costs
7. Prepare to engage in life-long learning.	18. Capture key learning in project closure and produce a personal plan to for its future application and development.

TABLE II. HOW RIVERWATCH ADDRESSES PMBOK KNOWLEDGE AREAS

PMBOK Knowledge Area	RiverWatch Learning Experience
1. Organizational influences: the project environment	1. Work within a programme structured of multi-year stages and sub-projects with dependencies 2. Resolve the relationship between project, programme and organisational goals
2. Project life cycle and processes	3. Understand the organisation of the RiveWatch programme and its communication 4. Apply agile lifecycles in a real-world multi-subproject environment to manage risk
3. Development of critical thinking	
a. Development of critical thinking Integration	5. Integrate mechanisms to manage the project effectively within the RiverWatch programme 6. Apply planning and change control to achieve a real-world product within constraints
b. Scope	7. Collect client requirements accurately and unambiguously 8. Work with the client and proactively elaborate requirements 9. Use a WBS to ensure nothing is omitted or duplicated
c. Time	10. Use a Gantt chart to allocate activities and manage their dependencies and timing 11. Manage real-world resource constraints in the project plan
d. Cost	12. Create a simple business case and project budget
e. Quality	13. Apply quality planning and control to achieve product acceptance and client satisfaction
f. Human resources	14. Assign work, motivate the team, monitor performance, make decisions and manage time
g. Communications	15. Apply taught theory to real client communication, team meetings and presentations
h. Risks	16. Identify, analyse and manage real-world project risks and handle their impact
i. Procurement	17. Budget for, specify and procure engineering components
j. Stakeholders.	18. Manage the expectations of a client, other teams and technical stakeholders.

TABLE III. HOW RIVERWATCH ADDRESSES KEY TRANSFERABLE SKILLS

Transferable skill	RiverWatch Learning Experience
1. Development of inter-personal skills	1. Work with others in a group project and with other teams in a multi-disciplinary environment
2. Experience of self-management	2. Manage own work and motivation to meet the project plan and team commitments
3. Development of critical thinking	3. Research and analyse project requirements and solutions, reflect learning in logbook, write report
4. Development of communications skills with others.	4. Work in a group environment to make decisions, control project interdependencies, present achievement to a client and produce technical and user documentation.

V. EVALUATIONS OF STUDENT LEARNING

At the end of the project management course each student produces an individual reflective report that describes their own evaluation of the project and what they learned from it. There were 40 students in 2013 and 56 students in 2014. This section explains how an analysis of the student reflections on their learning using grounded theory [24] provides an assessment of the pedagogy of the course.

Student learning from their reports was initially coded into specific learning points identified by the students from their project experience, i.e. what they did. Using concurrent data generation and analysis these were then coded into project management skill categories, which was complete when student learning fitted all the categories identified, yielding 618 reflections. This eliminated the trite repetition of textbook theory by verifying each learning point from direct evidence cited in the report, for example, "I found that referencing the plan was useful for drawing attention to forgotten tasks. It was easy for us to focus on the technical implementation, while neglecting components such as presentations and documentation."

Two types of learning emerged from this coding: reinforcement learning and reflective learning. Reinforcement learning is where students applied their learning and gained a positive outcome that reinforced it. Reflective learning is where students failed to gain a positive outcome from a key learning point but through reflection learned from their mistake. For example, some student projects followed their project plans while others did not, with students that did not learning on reflection that more investigation was required to obtain a successful plan. Reflective learning does not indicate poor pedagogy, as learning from making mistakes is a powerful way of learning [26]. However, it indicates where further research into the taught element is required.

The learning was then further coded to understand the type of project experience that drove it in order to see whether the assertions of using a real project made in previous research can be supported from RiverWatch. To do this, each learning point and the evidence for it were examined to determine the generic mechanisms driving the learning point. The results of our analysis and its consistency over two years are presented in the next section. The two graphs of results on the next page are explained the text on the following page.

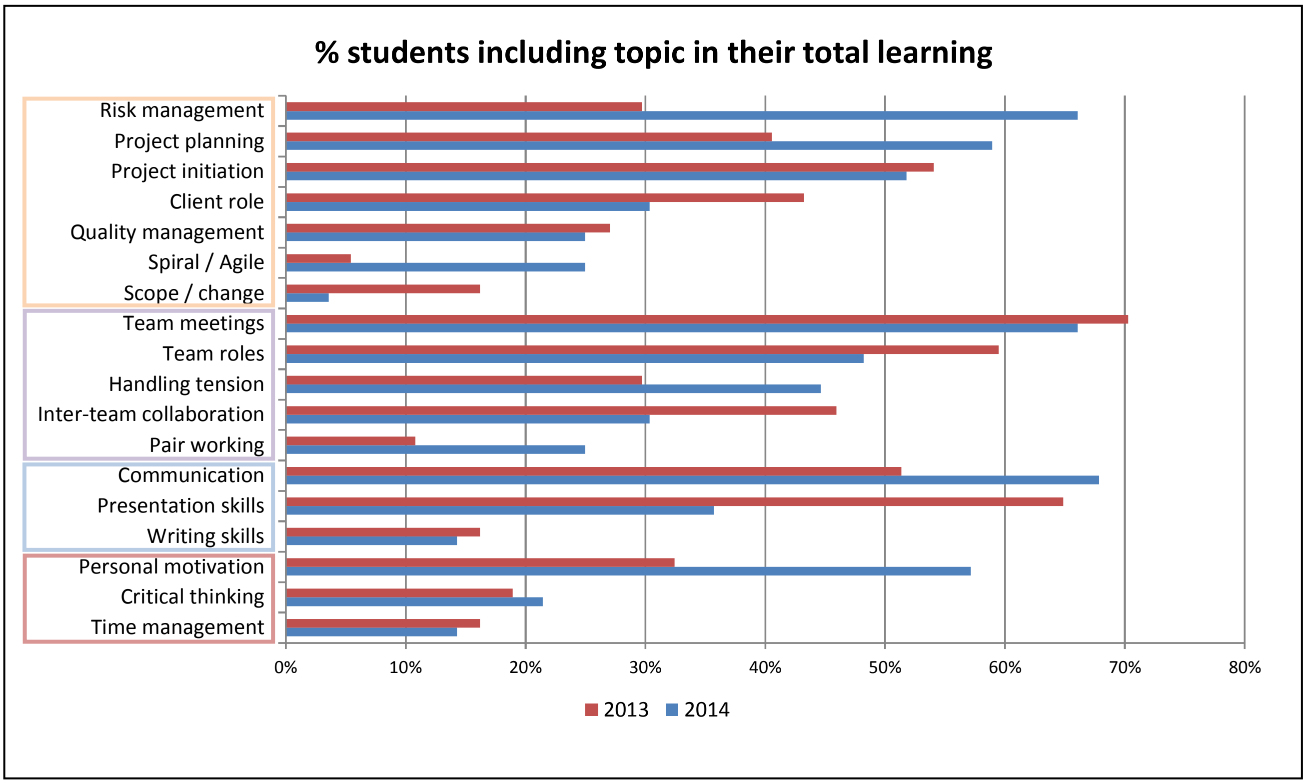

Fig. 1. Total learning points grouped by the skills shown in TABLE IV.

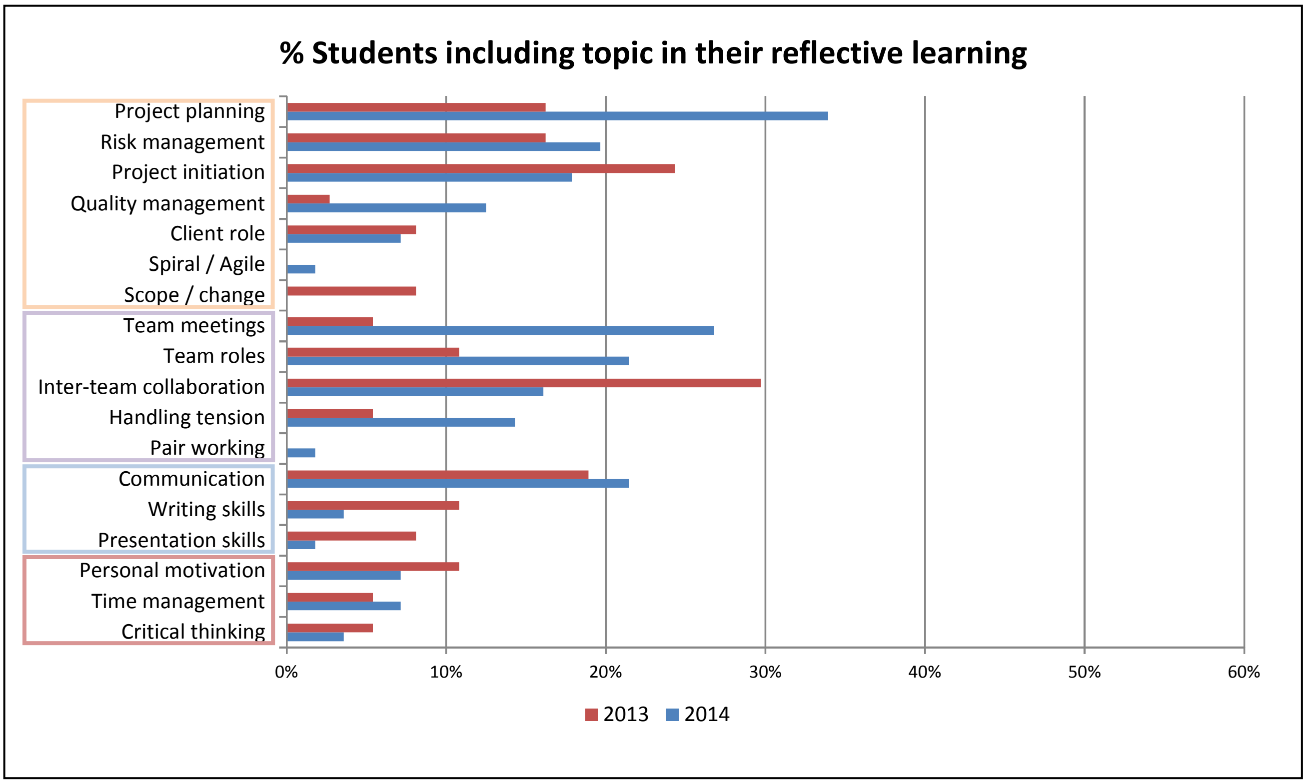

Fig. 2. Reflective learning points grouped by the skills shown in TABLE IV.

VI. Evaluation Results

The student learning points from the above evaluation are presented as total learning and reflective learning. The total learning is grouped into four skill areas. Following this, the experiential source of this learning is presented.

A. Total learning points

Fig. 1 summarizes all the learning topics identified from the analysis by the percentage of total students reflecting on them in their final reports in 2013 and 2014. These are grouped into the four skills areas and then ordered from the largest number of topics to the smallest in 2014.

The average number of topics reported by each student in each skills area is shown in Table IV.

TABLE IV. TOTAL LEARNING POINTS IN FOUR SKILLS AREAS

Skill area	2013	2014
Project management skills	2.2	2.6
Team working skills	2.2	2.2
Communication skills	1.3	1.2
Personal working skills	0.7	0.9

The summary of student learning by skill area in Table IV shows the consistency across the two years. It shows that learning transferable skills through the group projects is on par with learning project management skills. Personal motivation dominates the personal working skills.

B. Reflective learning

Fig. 2 summarizes the learning topics identified by the percentage of students reflecting on what they learned from their mistakes. (Reinforcement learning makes up the difference between Figs. 1 and 2).

The total number of reflective learning topics went up from 1.9 in 2013 to 2.2 in 2014, with most topics at one per five students or below.

C. Sources of learning

The experiential sources of the students' learning are shown across the two years for each of the four skill areas in Figs. 3 to 6. This was determined by examining the experiential context of the learning previously analyzed. This addresses the question of how much learning comes from the real-world group project with a real client with programme complexity verses self-learning.

As might be expected, personal working skills have a significant self-learning component. The other key skill areas, especially the transferable skills of communication and team working are predominantly learned from the real group project. Communication and project management skills had a significant real client component. The real-world group project learning has increased in 2014 in all cases except team working, where it is insignificant.

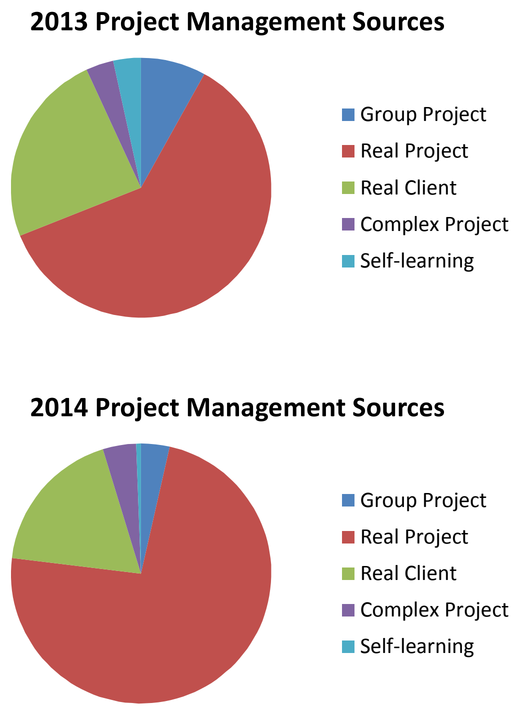

Fig. 3. Project management skills learning sources 2013 & 2014

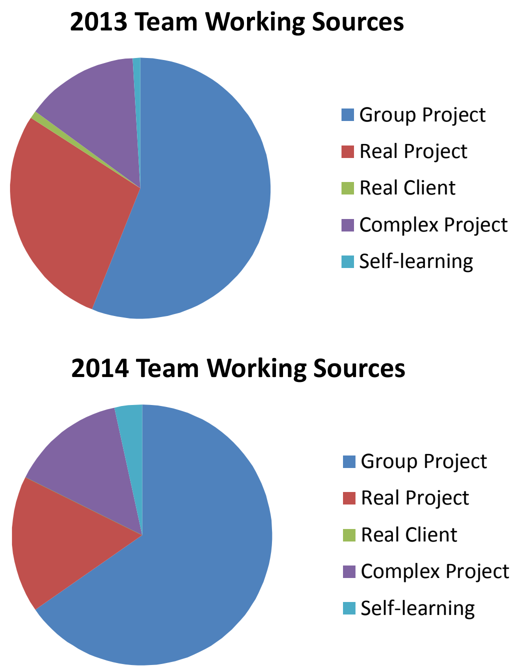

Fig. 4. Team working skills learning sources 2013 &2014

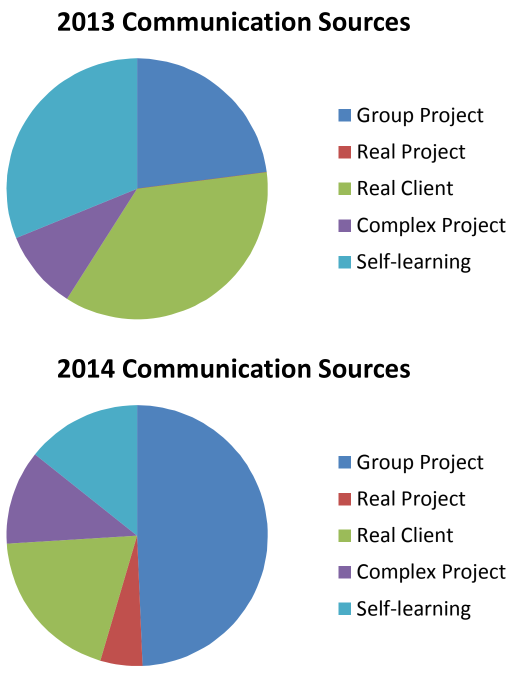

Fig. 5. Communication skills learning sources 2013 & 2014

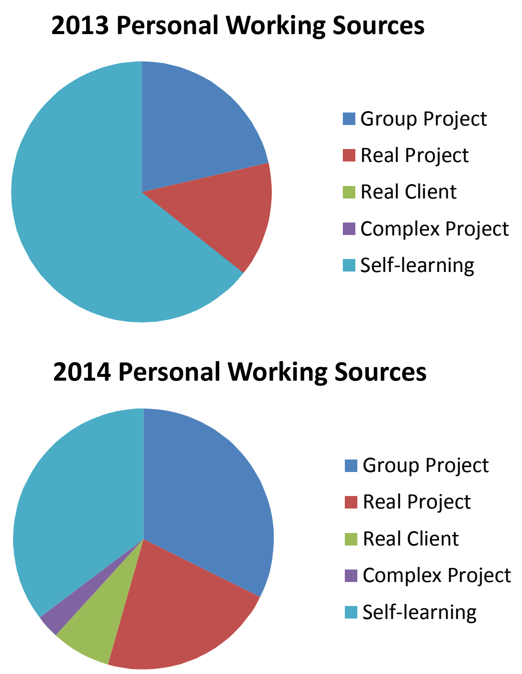

Fig. 6. Personal working skills learning sources 2013 & 2014

VII. Significance of Results

The evaluation results support the effectiveness of improvements made in 2014 described in section IV. High levels of reflective learning on project initiation and inter-team collaboration in 2013 were significantly reduced in 2014. Reinforcement learning of communication increased in 2014, reflecting its wider application beyond just presentations. Reinforcement learning of risk management doubled and there were fewer changes to project scope resulting in reduced reflective learning from this.

The evaluation of reflective learning also reveals two unexpected regressions in 2014. The first is in team working, where a timetable conflict was introduced by a change to another course that increased reflective learning due to fewer meetings being scheduled.

The second is the increase in reflective learning in project planning. This is dominated in both years by learning the truism that original plans and estimates often don't survive in a real project. Further research is required to identify the cause of this, but it may be due to more detailed planning being practiced in 2014.

A summary of the explanations of the differences in total learning is shown in Table V.

The sources of learning identified show that all four key skill areas acquired through the RiverWatch project derive predominantly from the students' direct experience of group working on a real project with resource constraints, deadlines, hard measures of success, a real client and complex characteristics, such as, stakeholders, inter-dependencies and multiple stages. The amount of self-learning reduced from 16% in 2013 to 10% in 2014. Further research is required to identify the cause of this, and will be part of our future work.

TABLE V. Explanation of Changes in Total Learning

Learning topics	Change between 2013 and 2014
Risk management Project planning Spiral/Agile	These project management topics were all taught more practically in 2014 resulting in an increase in learning
Team roles Inter-team collaboration Pair working	The first topic scored lower in 2014 due to calendar conflicts, while inter-team collaboration saw a reduction in reflective learning and pair working increased
Communication Presentation skills	Communication was taught more broadly in 2014, reducing the focus on presentation skills
Personal motivation	Increased to become a significant learning point issue in 2014, possibly reflecting less mature and overseas students than in the 2013 class
Client role Scope/Change	The class lecturer and tutors played a stronger role in 2014, possibly diluting client focus, but reducing scope change due to problems.

VIII. Summary and Conclusions

This paper has shown how teaching project management through a real-world project has addressed the needs of the engineering profession and covered the scope of the project management body of knowledge. The analysis of the students' personal reflection shows the key learning points achieved through the course and indicates where further adjustments will be beneficial.

This analysis corroborates previous research in showing that the generic transferable skills are rated by students as important learning [19][20]. Communication (including presentation skills) is the highest learning topic reflected by both quantity and importance, with team working also significant in the total number of generic transferable skill reflections.

Project management skills are also rated highly, with project planning, project initiation and risk management being the top six important learnings reflected by students.

The research also shows that learning can be improved by focusing on the reflective learning points to enable greater reinforcement learning. Key points to take forward from this are to ensure the reflective learning does not represent over-challenge and to review key topics such as project planning and team working to ensure student motivation is maintained. The precise pedagogy that increased learning from the real-world project in 2014 also needs further research.

We conclude that the use of a real-world project has been a success in addressing the IPENZ non-technical attributes, as reflected in student learning. The students' reflections provide direct evidence of learning from the real-world project, with group working and a real project being the biggest drivers.

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