DEVELOPING STUDENT META-COGNITION IN A DESIGN COURSE

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Abstract - *In the 1980s there was the proposal that reflective practice can help with developing professional skills. To encourage the development of self reflection and ultimately meta-cognition related to project and design work, undergraduate electrical engineering students in a non-capstone project course undertook reflection exercises on their group project. The instructor observed a range of abilities to undertake the reflections, with some not going beyond describing the work that they had done, whereas others started to show a deeper consideration and thinking about their project work. The main route for reflection was a reflection journal, where five entries were required over the period of the project. The choice of reflection topic was up to the student except in one entry case when a mandatory question on life long learning was asked. For each of the other reflections a suggestion was provided for a reflection topic. Other opportunities for reflection were included with questionnaires at the beginning and end of the course, as well as presentations including one describing one thing the group had learned. The individual experiences of students in a first major group project course allow a range of reflections to occur, from ideas about planning, group work, problem solving and design being potential areas for discussion. Evaluation here is restricted to the instructors observations and not a detailed analysis of the student's reflection work. This is an early examination of reflection and meta-cognition of the students but there are indications that students are taking the first steps in considering their approaches to project and design work.*

Keywords: Engineering design; meta-cognition; reflection; reflective practice; reflection journal; eportfolio.

1. INTRODUCTION

Meta-cognition can be defined as the process of thinking about thinking. Moving beyond this succinct definition it can be considered to be concerned with two aspects a) the awareness of cognitive processes and b) the control of those processes [1]. The interest in this for education can be the benefit to the individual learner with their self-awareness and approach to their learning.

When engineering design is undertaken there are a range of stages and associated thinking by those involved,

from project planning, through prototype creating, testing and problem solving and potentially to product manufacture. The path to learning design in engineering is mostly through experiential learning, so engineering programs provide opportunities to undertake design projects, whether through larger capstone projects, specific design courses or design exercises. Encouraging students to reflect on their thinking and approaches to the design problems can provide a way to increased self-awareness of their developing design ability. This meta-cognitive approach can help with developing a student's understanding, following the model of Kolb's learning cycle [2].

One model for learning to practice a profession like engineering or law is through learning all the technical details, and then understanding when and how to apply this set of detailed knowledge. This approach can be termed 'technical rationality' and was challenged by Schön in the 1980s as needing to be balanced and supplemented with 'reflection in action' or reflective practice [3,4]. He argues that effective professionals show elements of 'artistry' in their depth of knowledge and that this artistry should be developed through reflection and coaching.

Reflective practice in engineering has been considered as an approach to understanding student design efficacy [5]. In their work Adams et al [5] examined studies of engineering students' approaches to solving design problems and related them to the ideas of the reflective practice model of Schön [3]. The encouragement of the adoption of reflective practice has been argued necessary in other areas beyond design. It has recently been proposed as applicable for project managers as a way to cope with the current changing approach to products and services as well use in life- long learning [6].

In this paper approaches to encourage reflective practice in a one term third year project course are detailed along with some of the instructor's observations. The course's main aim is to design and construct an electronic device. In recent years examples of student projects have been: home monitoring and security systems, small autonomous vehicle that can parallel park, a system that allows an artist to introduce different spoken sentences when viewing a photographic portrait and a text message to braille interpreter. Although the central goal is to develop the student's electronic design and development experience, it was possible to introduce

reflection exercises and similar activities to encourage students to develop a deeper understanding of design and related processes. Encouraging the students to think about their approaches to the project and become more self-evaluating applies the idea of 'reflection in action', in an attempt to encourage students to develop meta-cognitive skills which they can use in future work. One key approach taken was to use reflection journals [7-8].

In this paper the course will first be described, details of the reflection journal will be given as well as other approaches taken for reflection. Most recently the introduction of questionnaires that can be completed by groups to look at how they will approach group work as well as looking back at the effectiveness of the group. Observations by the instructor on the various of the course reflection elements will then be given.

2. THIRD YEAR PROJECT COURSE

2.1.Course description

This one term course, ELEC3907 Engineering Project, is a compulsory third level engineering project for electrical and electronic engineering BEng students. The calendar course description is:

"Student teams work on open-ended projects based on previously acquired knowledge. Lectures are devoted to discussing project-related issues and student presentations. A project proposal, a series of project reports, and oral presentations, and a comprehensive final report are required.

Prerequisite(s): ELEC 2607, ELEC 2507, and ECOR 2606, and enrolment in the Electrical Engineering program.

Lecture two hours per week, laboratory six hours per week."

Project group members are randomly selected and are allowed to choose their own project, which is the construction of some electronic device. Some example project ideas are provided and some real clients can propose projects too, for example one year there were three artists that proposed projects. However, most project topics are the groups' own idea.

Student groups are typically 5 to 6 students, with the overall class size for the last two years having been between 125 to 140 students. The course is split into three sections and each section has a scheduled three hour laboratory session twice a week.

Initial laboratory sessions focus on health and safety, assembling and soldering of a microcontroller board, which is then tested to ensure to be working, including its RF communication capabilities. This is usually completed within the first three laboratory sessions after which the laboratory time is spent on designing and constructing the project.

Each project has a limit on the budget of \$100 though there is a small supply of basic components and use of those components does not count from the budget. Ordering of components is regularly done and deadlines

for orders are communicated to the students by a TA, who looks after the ordering itself. Because of lead times in orders and the limited budget students are encouraged to carefully select components.

Lectures were centred on information to supplement the project, either directly or indirectly. For example, programming the microcontroller, working in groups, basic approaches to design, including expert guest speakers. Three guest speakers have been brought in to the course including an RF designer to talk about electronic product development, an industrial designer to talk about life-cycles of products and an engineering ethicist who's speciality related to unmanned vehicles and discussed when decision making in vehicle systems have to be programmed that could lead to life and death decisions being made by algorithms. These speakers broadened the general awareness of product development. Other lecture sessions were spent with group presentations on project proposals, design reviews, a presentation where the group addressed the question 'one thing the group has learned' and a final group presentation of the project.

Assessment was through a group project proposal, an individual technical report, oral presentations, final project report, technical evaluation, individual contribution and a reflection journal.

2.2.Reflection Journal

Throughout the term each student is to complete five reflection journal entries. For two years these have been submitted and collected in an e-portfolio system. The topic of each reflection, except one, is the choice of the student, although a suggestion is provided with each reflection assignment. The one reflection that is mandatory for the students to reflect on is the penultimate reflection and this asks the student to reflect on how they plan to approach life-long learning.

The five reflection journals are spread across the term and the suggested topic can relate to the particular stage in the project the students may have just gone through. The questions are:

1. What did you learn about starting a group project and what would you change if you had to start your project again?
2. What is 'good design' in a product?
3. How have you approached the technical challenges in your project so far?
4. Over this project you have probably had to acquire new knowledge. Engineers are involved with a range of technologies that are constantly changing and evolving. Over a working lifetime this change can be significant. If you are responsible for your own knowledge development over your career, reflect on how you would try to manage that knowledge development? Consider also that an engineer may need to acquire knowledge and skills in areas such as accounting, management, law and other languages.

5. Looking at your project, as it currently is, critically assess it. What changes in the design would you make to your project to improve it and explain why?

Reflection 4 is the mandatory question.

Submitted reflections were done via the University's eportfolio system that provided ways to upload images and videos. They are shared with only the marking course instructor and not with other students. This allows for open discussion of the topic or subject being reflected upon.

2.3. Other Reflection Approaches

Within the course there were other opportunities for students to be encouraged to think about their approaches to the project. These included an initial questionnaire for the group to fill in together at group formation time; a final group evaluation as well as an individual self-evaluation questionnaire. Oral presentations to the class were part of the course and towards the later part of the course one presentation addressed the specific topic of 'one thing the group has learned'.

The group formation questionnaire asked about group membership and the project to be undertaken, but it also prompted the group to set some ground rules. The questions doing this prompting were:

1. How often will the group meet?
2. Is there a group leader?
3. How will all contribute to the discussion?
4. How will decisions be recorded?
5. How will information be shared?
6. How will roles be respected?
7. How will the group handle poor time keeping (late arrival, early leaving or not turning up)?
8. What does the group consider to be characteristics of a good team member?

The second questionnaire on group evaluation was completed with an instructor for the class and the questions with the choice of four answers for each are shown in Table 1.

Table 1: Final group evaluation questions and answers.

Did you achieve your various group deadlines?	Often missed them	A few were missed	No important deadlines were missed	No deadlines were missed
Did you achieve your original technical goals?	Missed most	A few key goals were missed	No important goals were missed	All goals were reached

Rate your overall group attendance in the lab.	Someone was late, left early or absent every session	Someone was late, left early or absent each week	Occasional lateness, early leaving and absence once a month.	Only one or two shortened attendances or absences over the term
Did differences of opinion and any conflict within the group get resolved?	Rarely	Occasionally	Most of the time	Always
How would you rate the trust and dynamics within the group?	Little trust and poor interactions	Some trust and minor conflicts	Dependable team members and mostly good interactions	Very dependable team members and very good interactions
Overall rate your group performance	Poor	Developing	Accomplished	Exemplary

After completing the group evaluation questionnaire each student was asked to complete on their own and individual assessment. First three questions were asked with four possible responses for each, see Table 2. There was also a chance to acknowledge an individual contribution with the question:

- In your opinion who was the group member that provided you and/or the group with significant input on technical matters, and/or who showed leadership (does not need to be a designated group leader). You can name none or more than one. Briefly explain why.

Table 2: Final self assessment questions and answers.

Did you achieve your various individual deadlines?	Often missed them	A few were missed	No important deadlines were missed	No deadlines were missed
Rate your dependability as you think it is viewed by your team members	Weak	Fair	Good	Strong
Rate your own performance in the group project	Poor	Developing	Accomplished	Exemplary

The questionnaire finished with a table where the dependability of each member of the team could be rated by the individual completing the form. The categories for each rating were: weak, fair, good and strong.

The presentation session titled 'one thing the group has learned', was presented by the students in the schedule lecture sessions and each group had a brief period of time about 4 to 5 minutes to present the point their group chose. Time for questions was allocated too.

In recent years three guest speakers have been invited to the course each term. These were experts in areas that connected to the students work in the project, but also with their future employment. The RF designer explained the approach to design, certification and release of an electronic product. The industrial designer has discussed lifecycle analysis, included the effective and changing value of a product from the start of the product through to its disposal. As well the challenges inherent with product disposal and recycling were discussed. The engineering ethicist raised issues on the constructing of the decision making process for autonomous vehicles in collision and collision avoidance situations. This talk moved beyond the more conventional ethical discussion of professional conduct and responsibility.

3. OBSERVATIONS AND DISCUSSION

Observations by the author, who was the course designer and an instructor will be reported here. At the time of writing there was no ethics clearance for reporting student work, so instead there will just be general observations.

The aim of the course was to introduce engineering students to project work and to draw on knowledge they had gained in the terms prior to the course. However, as can be seen here there was intent to encourage the students to develop and think about the broad range of skills and knowledge with regards to designing of electronic items, as well as managing a group project.

The intention of the reflection journal was to encourage the consideration of approaches and challenges encountered. The approaches taken to designs or resolving technical problems are all opportunities for reflection and ultimately meta-cognitive understanding. Students reflect to varying degree and there was a significant number of students who responded, especially initially, with descriptions of the work done in the period since the last reflection. For those that did reflect the focus of the reflection often centred on some of the more challenging aspects encountered over the period. So this can move from the planning stage, to construction and testing and then to the challenges to finalizing the project and bringing it to a finished working prototype. The suggested questions are sometimes used as the basis of reflections. Occasionally a student would answer in two part, addressing the discussion question in addition to detailing the work done in the course. With instructor marking and feedback some of those who would only describe the work done in early reflections did make attempts in subsequent submissions to reflect and discuss. For some, they did not make the move away from describing.

The mandatory question on knowledge management over a career produced interesting responses. There was general acknowledgement that this was important. Self learning through internet based resources was commonly listed as the process of how to gain access to new knowledge. Explicitly videos, technical news sites and

blogs were mentioned by some. Other routes mentioned were through the employer, other colleagues, personal and professional networks and formal education courses. The assistance professional organizations can provide was often overlooked. A few students indicated they would keep their own learning notes. A significant number indicated interest in business knowledge development including mentioning the intent to following formal business education, such as an MBA. In general the responses to the question seemed embryonic, perhaps not surprising as the majority will not have worked for long, if at all, in the field of engineering. The full appreciation of the need to stay current may come with time and experience. However, it is perhaps important at this undergraduate stage to encourage the consideration that strategies to learning for technical and professional development over a career is needed. When first encountering individual or professional development plans through an employer or professional organization the student will perhaps be better prepared.

The use of an eportfolio for the reflection journal is effective in three ways. One is administration of the written materials. They are accessible online and that helps with easy access for the students and as well as the instructor for marking. Another benefit is the ease to which images and videos can be included in the reflection. Photographs of working parts of the project, or pages of notebooks, often with sketches, were included by students. Similarly, videos of parts of projects moving or with changing displays can be included to illustrate points. Finally, the portfolio has the collection of the submitted reflections which can allow a student to reread previous submission providing a retrospective view of the project and the development of the student opinion on it.

The questionnaires at the beginning and the end of the project acts as prompts to learning processes. The initial questionnaire serves a practical purpose, for example project outline, whether there will be a nominated leader, knowledge sharing routes. However, they questions are also prompts to encourage the reflection by the newly formed group on how they will organize themselves and deal with matters that they may not initially think about, such as how will all members be able to contribute to discussions, how assigned roles will be respected and how tardiness will or will not be tolerated. Though the questions are practically based there was an intent for them to act as a trigger for the individuals to think about what could happen through the process of the project and to think up front about potential issues. These questionnaires were only introduced in the last offering of the course and they come partly from the instructors observation of points of potential tension or conflict within a group. Raising the discussion of these items early on in a group's formation is not only beneficial to avoid interpersonal conflict within a group, but also it helps to establish the protocols that group members can think about when undertaking their work.

The concluding questionnaires (group and individual) is self-reflective and is intended to be a form of debriefing and examination of what needs to be corrected in subsequent group work situations, such as a co-op position, capstone project or in employment. It also encourages the early adoption of reflection in project work and can lead to meta-cognition on the approaches to undertaking project work. The involvement of the instructor sitting with the group and asking the questions allows small scale discussion and perhaps a more accurate answering of the questions. It was interesting to see sometimes groups being open about their poor attendance or the discussion on their self evaluation on the performance of the team. The instructor was non-judgemental with the responses and encouraged discussion and gathering of all views.

The presentation session on 'one thing the group has learned' was another attempt to prompt the group to discuss what valuable experience they wanted to highlight. By then sharing this with the rest of the students on the course this series of presentations provides a broad and rich evaluation of different learning experiences. These can range from technical to aspects of project management and working within a group.

The guest lectures proved to be stimulating to students and sometimes were discussed in submitted reflections. Each speaker was selected and encourage to discuss work that may not be commonly covered in other lecture courses that the students had met or would likely meet. There was the practical aspects of electronic product design for manufacture, the cost of disposal of a waste product that at its time of purchase may have had a significant value, or the philosophical dilemmas that can occur when controlling an autonomous vehicle. Feedback from students either verbally or by the reflections indicated that students were thinking about the content of these guest talks. At the core these talks were to take a step back from technical detail of design and to look broader at the potential impact on product creation.

4. CONCLUSION

Attempts have been made to encourage self-reflection and meta-cognition in a non-capstone project course. The main approach has been to use reflection journals but also to complement with questionnaires at the beginning and end of the course. The work reported here describes approaches to give the chance for students to reflect and move to meta-cognitive understanding, it includes instructor observations only and further detailed analysis will require ethics clearance.

The depth of reflection in the portfolio submissions can vary, from a number of students who were not reflecting but rather describing what was done, to students who were in the early stages of reflection over to a small number who are moving to deeper reflection and meta-cognition. The use of a specific reflection question on life long learning was used to initiate the idea of developing knowledge in professional life.

A questionnaire at the beginning of the project was used to make students consider how the group will operate in an effective and respectful way. There was also a final questionnaire that provided group evaluation and self-evaluation. These were introduced to ensure there were group-level considerations to reduce the risk of interpersonal conflict, to help with planning and to evaluate the efficacy of the group. Helping both in this course as well as future group work. This showed to the students the importance of the less technical aspects in a project course, where at a naive level the technical content could be consider the only point of importance.

Although a project course could be considered by students as a fundamentally technical course there are key aspects that can provide understanding to approaches in design, problem solving and group work. By implementing a few key processes to allow ways that students can examine their own experience in a course. Further by including expert guest speakers to talk broader about product design, manufacture and disposal there was an attempt to create a wider perspective of product design. By introducing this into an early group project it provides experience and reflection opportunities that can help with future project work. This is sometimes recognized by students and commented on in some of the final reflections. It can also start to encourage students to think more at a meta-cognitive level, for example thinking about how they will approach group operation, how ideas in a design will be collected and approaches to problem solving.

Although some students will move towards metacognitive thinking at different rates, there is the opportunity in project courses to start the process, or build on existing experience, so that the student is better prepared for design and engineering work in the future.

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