Validating Student-led Learning Initiatives in Problem Solving: a cross institutional case study

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CONTEXT

The role of students and tutors as valued partners in engineering education has become an integral part of the mechanical engineering Design Graphics and Communication (DG&C) course within the University of Adelaide. As the DG&C course transitioned towards more democratic student-led directions, the teaching team developed a framework to facilitate students' learning; the Optimising Problem Solving (OPS) pentagon. The OPS pentagon was introduced in the 'Thinking Like an Engineer' workshop at the 2014 AAEE conference, where the efficacy of OPS was put to test by a group of 42 educators, including 40 engineering education academics. The workshop was highly successful, providing valuable positive feedback as well as a verifying that the OPS pentagon is an effective framework to facilitate democratic student-led learning.

PURPOSE

An invitation, resulting from the AAEE workshop, for the University of Adelaide tutors to facilitate a problem solving workshop for first year engineering students at the Australian Maritime College provided the opportunity to engage new students in the creation and ownership of their own learning. The purpose of this paper is to present preliminary perceptions from students and tutors on their co-participatory learning in critical thinking and problem solving, gained from this workshop.

APPROACH

The approach used in this study is grounded in Action research in which an iterative, systematic, participatory, and empirically based process is applied to improving practice. As part of this process, students have a dual role as learners and as educators while educators have an additional role as learners.

RESULTS

Results from this study indicate that students were clearly able to identify areas of learning and skills development resulting from participating in the workshop. Transferability of learning was also demonstrated through students’ self-identified application of extended problem solving capacity to their project work.

CONCLUSIONS

Conclusions drawn from this study, with participants from a comparable cohort of first year engineering students in a different university setting, supports the validation of the Optimising Problem Solving pentagon as an effective framework for facilitating democratic student-led learning. These results compare favourably with the verification of OPS by academics in 2014.

KEYWORDS

Students as partners, Action-based research, student-centred, co-created curricula, transferability.

Introduction

Learner-centred or student-centred education has long been recognised by educators as a powerful approach to promoting student ownership and self-regulation of their own learning. Felder (2012) traces the theoretical foundations of student-centred approaches in learning to 19th century philosopher and educator John Dewey (see for example *How We Think,* 1910), social constructivist and Russian philosopher Lev Vygotsky (see for example *Mind in Society,* 1978, English translation) and cognitive constructivist and Swiss psychologist Jean Piaget. Research of the literature on approaches later developed from these early theorist indicate the “superiority” of learner-centred education (Felder 2012) and cite the enhancement of students “motivation to learn, retention of knowledge, depth of understanding and appreciation of the subject being taught” (Felder and Brent ,1996 p.43).

However, the changing roles of engineering educators in one particular First Year mechanical engineering design course has evolved from accepted views of student-centred education to more democratic student-led directions. These initiatives have developed into an approach in which some of the original students who were given the opportunity to peer lecture also created a pathway, for themselves and future students, to become undergraduate tutors. At the same time successive tutor teams, students, lecturers and alumni have also co-developed course material to enrich student learning. In this particular course the notion of co-created curricular and student-led approaches in learning and teaching and learning originated with students themselves in 2008, and was then conceptualised within a framework of Freirean democratic philosophy (Missingham & Matthews, 2014) (see for example Freire, 2005 *Teachers as Cultural Workers*) and grounded in Vygotskian traditions of social constructivism.

Such co-created curricular and student-led approaches have now come to be known as to as ‘students as partners’, and has recently been referred to as a ‘”hot” topic internationally’ (Healey *et al.,* 2016). However, one of the aspects that appears to distinguish the work of the particular approach discussed here is the student/tutor led development of new frameworks for learning in Engineering Education.

The role of students and tutors as valued partners in engineering education has become an integral part of the Design Graphics and Communication (DG&C) (Mech.Eng.1006) course within the School of Mechanical Engineering at The University of Adelaide. A successful part of this initiative has been the devising of various learning activities designed to scaffold student learning on how to optimise their problem solving approach, given a particular 'Engineering Problem' within the DG&C course. As the DG&C course transitioned towards more democratic student-led directions, the teaching team developed a framework to facilitate students' learning i.e. the Optimising Problem Solving (OPS) pentagon. The OPS pentagon was introduced in the 'Thinking Like an Engineer' workshop at the 2014 AAEE conference, where the efficacy of the OPS pentagon was put to test by a group of 42 engineering education academics. The workshop was highly successful, providing valuable positive feedback as well as a verifying that the OPS pentagon is a highly effective framework to facilitate democratic student-led learning. Following the success of this workshop in meeting the standards of experienced educators, learning activities in thinking critically and problem solving were either strengthened or adapted, then implemented in the second semester 2015 DG&C course.

An invitation, resulting from the AAEE workshop, for the Adelaide tutors to facilitate a problem solving workshop for first year engineering students, in Engineering Design and Communication at the Australian Maritime College (ACM). This invitation provided the opportunity for three of the current tutors; two of them undergraduate students and one tutor now a postgraduate who began tutoring as an undergraduate student, to deliver an OPS workshop to a comparable first year design engineering course at a different university. The ACM workshop not only provided the opportunity to engage new students in the creation and ownership of their own learning but serendipitously also created the possibility of validating transferability of the OPS framework.

Purpose

The purpose of this paper is to present preliminary perceptions from students, tutors and lecturers on their co-participatory learning in critical thinking and problem solving, gained from the AMC workshop.

The Workshop

The workshop was specifically designed to create a culture of knowledge sharing and reciprocal learning between students and tutors, tutors and lecturers, lecturers and students, and students and students. In the workshop students were introduced to the Optimising Problem Solving (OPS) framework as a means to assist them in working "towards a broader, more complete solution" (Willison et al. 2016) when addressing engineering problems.

Aim

The aim of this workshop was to assist students

- make connections between technical engineering practices, teamwork and collaboration, and professional engineering management and communication,
- strengthen their capacity for thinking critically and creatively, and for solving problems within engineering settings,
- develop their understanding of how graphical and rhetorical communication are inter-related, and
- apply a new framework for optimising problem solving.

Workshop Approach

The problem presented was "a task involving the description of a hidden object to a team of illustrators" (*ibid)*. Teams, which were already working together as part of the design course, were divided in half. One half of the team describes the object and the other half of the team sketches the object in third angle orthographic projection.

- The problem was introduced by three near peer tutors from the University of Adelaide
- Prior learning useful to the students, in the AMC Engineering Design and Communication (JEE113) workshop, was revisited to support the new learning.
- Students were encouraged to communicate the processes and outcomes of the workshop exercise in a short feedback discussion at the end of the workshop.
- New learning (for example use of the OPS pentagon) was scaffolded throughout the feedback discussion, as a means to encourage student recognition of the steps they took or could have also taken in solving the problem
- Students were asked to reflect on their learning from the workshop, in a subsequent workshop later in the course.

To assist student understanding of teamwork, communication and problem solving they were given a single page handout showing Optimising Problem Solving Pentagon; one side illustrated the full OPS pentagon with descriptors of the facets included (as seen in Figure 1, below), the other side illustrated OPS without the facet descriptors to allow students to record comments during debriefing and feedback.

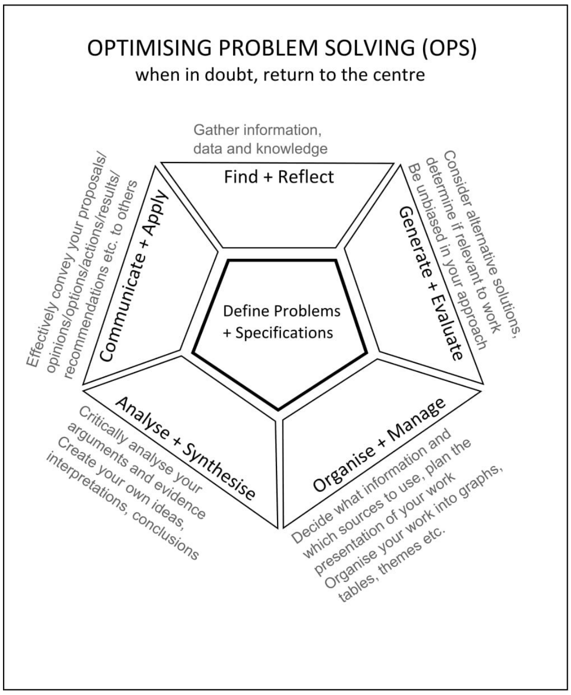

Figure 1: The Optimising Problem Solving pentagon (Mechanical Engineering Tutors, 2014) with descriptors for each of the facets included.

Students were also provided with guidelines on the aims of the exercise, how to approach the problem and the expected outcomes of the exercise. Specific outcomes aligned were aligned with the aims of the workshop and articulated in a "takeaway" form.

Student participants in the workshop will take away;

a) practical experiences to assist making connections between authentic engineering practices, teamwork and collaboration, and professional engineering management and communication
b) techniques that can be applied to developing their capacity for thinking critically and creatively, and for solving problems within engineering settings
c) an understanding of how graphical and rhetorical communication are inter-related
d) a new framework, developed by their peers, for optimising problem solving

Methodology

The approach used in this study is grounded in Action research in which an iterative, systematic, participatory, and empirically based process is applied to improving practice. The emphasis on critical inquiry and the iterative nature of action research fits with constructivism's characterisation of a spiral building of knowledge (Bruner, 1960), the importance of reflective practice (Schön 1983, Dewey 1933) as well as with iterative nature of the engineering method (Dowling, Carew and Hadgraft, 2012). As part of this process, students have a dual role as learners and as educators while tutors and lectures both facilitate the learning and have an additional role as learners.

In this approach, students were asked to reflect upon their learning from the workshop, through the use of three key questions. The reflections were specifically devised as part of the intended learning rather than as a separate survey, and were both optional and non-assessed. Two questions were designed to promote analytical and evaluative levels of reflection on the problem solving process and exercise outcomes. The third question aimed to encourage student extrapolation of their new understanding by applying it to the design project of their course. During the workshop, tutors facilitating the approach and the lecturers present, were asked to observe the learning process and outcomes, and later reflect on their observations.

Open coding (see Corbin, 1990, Glaser and Strauss, 1967) has been applied to the responses, given by students, in each of the three reflective questions to allow initial categorisation of the information. Identifying categories within the reflections allows the possibility of eliciting new perspectives, previously not considered (by the practitioners), for example, one area emergent from the information was variously identified in terms of critical thinking, analysis, problem solving, reflecting and evaluating; these themes were able to be categorised as "Process". In this paper "Process" refers to a range of cognitive and intellectual processes that have been articulated by the students. The use of open coding for this study also allows for future examination of the information through axial coding or through selective coding (Strauss and Corbin, 1998), if desired.

Results and Discussion

Each of the questions were devised as a crucial step to engage students in higher levels of critical reflection. However, the questions also serve as indicators for potential further improvements in learning and teaching practice.

An examination of the results revealed a number of identifiable themes or categories. In the first and second reflective exercises the themes that emerged were identical. These categories were identified as communication, process, teamwork and design graphics as seen in Table 1, below. However, seven responses to "Three skills I developed further" were considered invalid as the intended meaning was unclear (refer to Table 2A in the Appendix for further details).

Table 1: Categories and number of responses given in student reflections on "Things I learnt" and "Skills I developed further" ***(* 7 invalid responses not included in tabulation).***

Categories Responses*	Communication	Process	Teamwork	Design Graphics
Three thing I learnt n=67	21	30	13	3
Three skills I developed further n= 61**	21	20	10	3
Total	42	50	23	6

The responses given to both questions reflect strong orientation toward students building their own knowledge in communication and process. Process responses reflected a range of answers that can be loosely identified as identified in terms of critical thinking, analysis, problem solving, reflecting and evaluating. Detailed responses can be seen in Table A1 and Table A2 of the Appendix, and include insights into student thinking such as "communication is important when coming to solving a problem", "problem solving involves communication because you need to be able to communicate your solution", "communication is key when working in groups" and "that communication is the greatest tool"; comments that indicate a recognition of the interconnectedness of concepts in thinking like an engineer. One of the tutors, a co-author of this paper, who facilitated the workshop highlights this student understanding of interconnectedness in his own reflections.

Luke, undergraduate tutor in DG&C:

> *”The workshop in the Australian Maritime College revealed students are willing and able to apply the OPS Pentagon. Despite only being exposed to the pentagon for a brief period, student feedback illuminated their interpretation of the structure and how it could be useful to them. The students stated the OPS pentagon is useful when “confronted with a problem” and in “reflection and problem solving”. Additionally, a number of students claim the OPS pentagon has been useful for aiding and facilitating team communication. That this is a common theme regarding the application of the OPS Pentagon is reassuring as the intended purpose of the framework is linked to the development of student understanding of ‘thinking (and communicating) like an engineer’.”*

Critical thinking, analysing skills and problem solving were identified by students as significant areas of learning and further skills development, as reflected in the following comments; ”lateral thinking and effective communication” “problem solving isn’t always some done at a desk with paper, it’s often rapid on the spot”, “importance of engineering analysis” and “how to view problems from different perception”.

Mei, senior tutor in DG&C:

> *“Responses from the students relating to their reflections on three things learnt and three skills developed were mostly revolving around communication and the ‘process’ of problem solving. Students’ self-assessment of the areas in which they were learning strongly supports our (the tutor) observations of the areas which they needed to improve. These responses support our ‘original’ reason for establishing OPS, thereby providing some level of validation of OPS as a tool for problem solving.”*

Teamwork responses also indicate the interconnectedness of learning that students recognised in the application of OPS as a useful approach in optimising potential solutions, for example, “without constant detailed discussion, group work becomes extremely difficult” indicates a link between process, communication and teamwork.

An examination of responses in the third exercise based on student reflections on application of OPS to the Autonomous Surface Vehicle design project six of the seven emergent categories were directly aligned to the individual facets of Generate and Evaluate, Organise and Manage, Communicate and Apply, Find and Reflect, Define Problem and Specification, and Analyse and Synthesise. The seventh theme which emerged reflected overarching or “big picture” thinking that, as with questions one and two, was categorised as process as seen in Table 2, below.

Table 2: Categories and number of responses given in student reflections on their use of OPS in their AMC Design Project

Categories	Generate and Evaluate	Organise and Manage	Communicate and Apply	Find and Reflect	Define Problem and Specifications	Analyse and Synthesise	Process
No. of Responses	7	7	8	5	4	5	7

The categories given in Table 2 were recorded in the order they emerged from the raw data. Interestingly, this emergent ordering is consistent with the non-directional and recursive Nature of the application of the OPS approach. Student reflections on their subsequent use of OPS in their Design Project indicate that they were able to transfer learning from the workshop to another setting for a different purpose. Responses exemplifying transference of learning from OPS include ”Generate and evaluate – evaluate issues which we may have with catamaran design -> not going straight or turning effectively -> consider installing keels”, “analyse and synthesise – trial and error testing of how we will connect the motor in place”, “organising to have all components complete in time” and “communicate with team mates about occurring problems and brainstorming solutions”.

Deepika, undergraduate tutor in DG&C, observed the following:

> *The students were prompted to think of ways to apply the learning outcomes of the workshop to their major design project. Importantly, they were not given specific examples of possible applications. Had specific examples been given, the students' imaginations may have been stifled. Instead, the students were left to come up with their own scenarios. This prompted more involvement in their own learning: they had to spend some time considering options rather than merely reciting information. A wide variety of responses emerged from this process. This finding highlights the fact that different students applied the learning to areas that were especially pertinent to them."*

Student capacity to transfer learning is also reflected in Process responses such as “improve on any disadvantages in design”, “use as a template against our report” and “use the pentagon when a problem arises”. The full range of student responses, related to the application of OPS to the design project, can be seen in Table A3 of the Appendix.

The concept of transferability or transference in learning is important in understanding the degree to which students have acquired certain knowledge and their capacity to apply that knowledge to different situations. Graaff and Kolmos (2003 p.658) highlight the need to ensure students “gain a deeper understanding of the … problem” and “must therefore acquire the ability to transfer knowledge, theory, and methods from previously learned area to new ones.”

Senior tutor Mei, reflects;

> *Responses to the question on how students applied OPS to their design project show transference of learning; excellent indications that they developed knowledge and skills from OPS and applied it to a different area of study. However, the responses provide us with few indications on how well OPS is working from them, or how OPS is improving their communication skills.*

Only one response, “There were several large hurdles which had to be overcome during the design. The implementation of the OPS was very successful in overcoming these.” provided a measure, in this case a qualitative measure, on how well OPS worked in its application to the ASV design project.

Despite this shortcoming student responses indicate that the method of approach, using OPS, is effective; especially given that students appear more aware of the areas in which they are deficient by identifying improvements they have made. Student capacity in developing awareness of their need to improve problem solving skills as well as their capacity to transfer new learning to other situation was also observed by the lecturers. As remarked by the AMC Engineering Design and Communication course co-ordinator;

> *Engaging students in problem solving activities in the classroom have shown to be an effective mechanism that engages students in active learning. It can be seen in this workshop when applying the OPS Pentagon- it provided the students an opportunity to engage in a more creative an interactive way with the 'task at hand'. It encouraged the students to work collaboratively with their peers while developing communication and reflective skills.*
>
> *Some weeks later the students embarked on their major Autonomous Surface Vessel project (ASV) and put the OPS Pentagon into action as part of the design tools in the project. The OPS allowed the students to take a problem-centred approach to design development and learning. The students reported the OPS enhanced their ability in group discussions to critically analyse and communicate their design thinking.*

Having students themselves identify these ‘areas of improvement’ significantly opens up their minds, attitudes and responsiveness to the learning and teaching of problem solving and communication, indicating that OPS is proving to be a highly effective ‘bridge’ to assisting them learn an essential component of the engineering method.

Conclusions

While OPS is designed to help students investigate a problem and improve the effectiveness of their communication, the exercises used in the Australian Maritime College, Engineering Design and Communication course workshop showed how the tool can broaden problem solving approaches and inspire more holistic thinking. Results of the workshop conducted indicate that OPS is proving to be a highly effective ‘bridge’ to assisting students learn an essential component of the engineering method.

OPS is a tool that provides small enough ‘bite size’ parts of the process that students can understand the information while applying it to their university project, as demonstrated in their responses to how they applied OPS to their Autonomous Surface Vessel project. The Optimising Problem Solving approach balances the abstract concepts from the Engineering Method and the Research Skills Development framework, with more practical direction, given in the descriptions of the facets, on what to do. The level of direction given, however, has been devised in order not to stifle autonomous learning, as evidenced by the clear indications students are applying OPS in their project in their own ways.

Students at AMC were of a similar age and stage of their engineering studies as the first year students in Mechanical Engineering at The University of Adelaide. Given that the workshop was not integral in their semester long Engineering Design and Communication course at AMC and that students responded well to the Optimising Problem Solving framework, it provides an indication that OPS is a highly versatile tool that may fit with any engineering design/ communication/ professional practice course with similar aims.

Additionally, the session at AMC indicates OPS is very independent, practical, relatable and applicable to first year mechanical and other related engineering students in general. Thus results from this study, with participants of a comparable cohort of first year engineering students from a different university setting, also validates the OPS pentagon as an effective framework for facilitating democratic student-led learning.

References

Bruner, J. S. (1960) *The Process of Education.* Cambridge, Mass.: Harvard University Press.

De Graaff E. & Kolmos, A. (2003). Characteristics of Problem-Based Learning. *International Journal of Engineering Education,* 19 (5)

Dewey, J. (1910) *How We Think.* Boston: D.C. Heath & Co.

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process.* Chicago, IL: Regnery.

Dowling, D., Carew, A. and Hadgraft, R. (2012). Engineering your Future: *An Australian Guide.Milton, Australia: John Wiley & Sons.*

Felder, R M. (2012). Engineering education: A tale of two paradigms. In McCabe, Panatazidou and Phillips (Eds.) *Shaking the Foundations of Geo-engineering Education* (pp. 9-14). London: Taylor and Francis.

Felder, R.M. and Brent, R. (1996). Navigating the Bumpy Road to Student-Centered Instruction. *College Teaching,* 44 (2), Spring, 43-47.

Freire, P. (2005). *Teachers as Cultural Workers: Letters to Those Who Dare to Teach*. Boulder, CO: Westview Press.

Healey, M., Flint, A., & Harrington, K. (2016). Students as partners: Reflections on a conceptual model. *Teaching & Learning Inquiry*, 4 (2), 1-13, 657-662.

Missingham, D. & Matthews, R. (2014). A democratic and student-centred approach to facilitating teamwork learning among first-year engineering students: a learning and teaching case study. *European Journal of Engineering Education*, 31 (4), 412-423.
Schön, D. (1983). *The reflective practitioner: How professionals think in action.* New York: Basic Books.
Strauss, A. and Corbin, J. (1998*). Basics of Qualitative Research: Techniques and procedures for eveloping grounded theory. (2nd ed.) Thousand Oaks, CA: Sage.*
Vygotsky, LS, *1978 Mind in society: The development of higher mental process.* Harvard University Press, Cambridge, MA.
Willison, J., Missingham, D., Cheong, M. Papa, T., Baksi, R., Shah, S. and Severino, G. (2016) *Optimising Problem Solving: student and tutor perceptions of problem solving within mechanical engineering*. Paper presented at the Australasian Association for Engineering Education Annual Conference, Coffs Harbour, NSW.

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Appendix

Table A1: Student Reflections on "Three things I Learnt"

Categories	Comments (n=66)
Communication (n=21)	• problem solving involves communication because you need to be able to communicate your solution *(Process)* • explain concepts back to the person to ensure it is understood correctly • communication is key when working in groups *(Teamwork)* • importance of communication • how hard it can be to communicate using audio only • lateral thinking and effective communication • how hard it can be to explain a design of something to someone who has no idea what it is or what it looks like • how to explain something without showing the person the object • communication is important when coming to solving a problem • giving precise instructions • listening when others talk • communication involves verbal, written and listening skills • importance of different communication methods • new method of team communication *(Teamwork)* • effective communication through the blind drawing exercise • team communication • clarity of details is important *(Process)* • that communication is the greatest tool • communication is key • learn how to communicate through blind drawing exercise • terms
Process (including analysis & problem solving) (n=30)	• problem solving involves communication because you need to be able to communicate your solution *(Communication)* • doing a draft is a good idea • stick to basics to get rough overview • lateral thinking and effective communication *(Communication)* • problem solving isn't always some done at a desk with paper, it's often rapid on the spot • importance of engineering analysis

	• how to view problems from different perception • accept others view and evaluate it to come up for better *(Teamwork)* • able to identify problems • a common misnomer is that engineering just involves producing one final answer • problem solving requires finding the best solution from a broad solution • new method of reflection/problem solving • continuous learning is important • engineering is a multi-layered profession • Problem solving skills (Pentagon Thingo) • Looking at a problem from another angle • How to manage time to effectively maximise learning, without wasted time. • clarity of details is important *(Communication)* • prioritising of details • reflection/problem solving • helps to know the strengths of team members/yourself *(Teamwork)* • various aspects of how engineers thing (think) and how they need to think differently than others. • what an engineering career involves • evaluating your own work is even more important than evaluating others • expect for there to be problems and allow time for problem solving • Modding (*sic* - modelling?) is very important • submission dates approach very fast • plans change a lot, final design depended on lots of things • importance of teamwork in problem solving *(Teamwork)* • critically analyse and think of a few possible solutions
Teamwork (n=13)	• communication is key when working in groups *(Communication)* • importance of teamwork • accept others view and evaluate it to come up for better *(Process)* • helps to know the strengths of team members/yourself *(Process)* • teamwork through the blind drawing exercise • working as a team to tackle a problem instead (of) by ourselves • time manage • good to organise/plan before commencing project *(Organise & Manage)* • will develop and evolve through the project • helps to know the strengths of team members/yourself *(Process)* • trust your team mates, you can't do it all • splitting workload between team mates works very well • importance of teamwork in problem solving *(Teamwork)*
Design Graphics (n=3)	• orthographic projection • 1^{st} and 3^{rd} angle projection • orthographic projection

Table A2: Student Reflections on "Three skills I developed"

Categories	Comments (n=61)
Communication (n=21)	• communication • clear communication • using means of communication other than sight • without constant detailed discussion, group work becomes extremely difficult (process, teamwork) • communication • better communication • different types of communication • communication • good line of communication • precise instructions • listening when given instructions for task • able to take the information and sketch the item from description • listening skills • how to provide feedback • communication • Communication • Delegation (process, teamwork) • Communication • My communication skills • To communicate in ways familiar to all persons present (CAD terminology) (Design Graphics) • Listen(ing) skills
Process (including analysis & problem solving) (n=20)	• time management • attention to detail • without constant detailed discussion, group work becomes extremely difficult (teamwork, communication) • analysis • lateral and critical thinking • critical thinking to resolve problems • patience • How to use tools in programs effectively • Figuring out the steps to create an object • Prioritising (…unfinished) • Delegation (communication, teamwork) • Patience • My strategical thinking skills • My knowledge on engineering • I now think in advance about problems which may occur • I have learnt to be patient while perfecting a design • Organisation (teamwork) • Learn to organise • Planning of schedules • Evaluate the specification
Teamwork (n=10)	• without constant detailed discussion, group work becomes extremely difficult • teamwork • distribute tasks across team members • teamwork • teamwork • teamwork skills • Teamwork • Teamwork • Delegation (process, communication) • Organisation (process)
Design Graphic (n=3)	• different projections in drawing objects • explaining an object in orthographic projection • to communicate in ways familiar to all persons present (CAD terminology) (communication)
Invalid/Meaning Unclear	• we built our prototype

(n=7)	• As above • Cost analysis • K.I.S.S. • Sanding • Cutting foam • Safety

Table A3: Student Reflections on application of OPS to AMC Design Project

Categories	Comments (n=43)
Generate & Evaluate (n=7)	• we built our prototype and discovered that it did not accommodate the prop/motor and we had to quickly re-evaluate • after the new design was built, we discovered that when the load was applied, the boat listed so weights had to be added to front and more foam to the (*illegible word)* • evaluate afterwards • generate and evaluate – evaluate issues which we may have with catamaran design -> not going straight or turning effectively -> consider installing keels. • generate and evaluate the sturdiness and buoyancy of the boat • generate and evaluate • evaluate
Organise & Manage (n=7)	• must organise roles better • must time manage better • organise roles for each member • organising and managing procedures • time manage + organise better • organising to have all components complete in time. • organise my schedules
Communicate & Apply (n=8)	• more communication • ask for help and advice more • clarify problem and concerns with lecturer more frequently • effective communication • I am sure I am communicating well and clarifying everything • communicate with team mates about occurring problems and brainstorming solutions • communicate with team members • have team discussion to resolve the upcoming problems
Find & Reflect (n=5)	• reflect on design will aide with discussion of ASV • can use Apollo 13 model for reflection in discussion • reflection (on) design • reflection and problem solving • reflection to help future work
Define Problem & Specification (n=4)	• problem definition and specification to satisfy required criteria • each team must reflect towards the problem and make a best choice out of it. • always return to problem specification • approach to solve/find solutions in arising issues
Analyse & Synthesis (n=5)	• analyse and synthesise on the mobility of the ASV • analyse each design concept with other research • analyse and synthesise – trial and error testing of how we will connect the motor in place • identify and analyse the problem that might occur in the project
Process (n=7)	• fix any design problems • improve on any disadvantages in design • there were several large hurdles which had to be overcome during the design. The implementation of the OPS was very in successfully overcoming these. • use the pentagon when a problem arises • use as a template against our report • always looking for things that might be a problem and then reflecting on the problem and design. • I will read through it and use the method to do it (the project)