MOTIVATION OF FIRST-YEAR ENGINEERING STUDENTS: A DESIGN AND BUILD PROJECT'S CONTRIBUTION

T.A. Brown[1]
University of Technology Sydney
Sydney, Australia

D.G. Rayner
Human Kind Psychology Pty. Ltd.
Sydney, Australia

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ABSTRACT

Hands-on 'design and build' projects have been advocated and reported to be essential components of practice-based learning for engineers for many years. The focus of most studies on the benefits of such design and build projects has been on technical/design skills. This paper is a reflection of practice in which the coordinator and teacher of a first-year engineering subject sought to find out how students' experience of a 'design and build' project might relate to their motivation and confidence to succeed as student engineers. Students in a first-year Introduction to Mechanical and Mechatronic Engineering subject (250-300 students in Autumn, approximately 100 students in Spring) participated in a 'design and build' project. The students worked in groups of 4-5 to design and build a small functional prototype wind-powered vehicle. After completing the subject, students completed an anonymous and voluntary online survey. The survey gathered some demographic information, asked several Likert-scale agree-disagree questions and encouraged students to write short explanations of why they agreed or disagreed and to describe their experiences. Student responses were evaluated and interpreted from expectancy-value theory of motivation and self-determination theory contexts. Students largely agreed that their participation in the design and build project had a positive impact on their confidence and expectation to succeed and on their perceived value of their studies. These results indicate that well-designed and supported design and build projects can have an important role to play in student motivation and successful transition to university.

[1] Corresponding Author
Dr Terry Brown
terry.brown@uts.edu.au

1 INTRODUCTION

1.1 Authors' background

This paper was written primarily as a reflection on practice by the first named author who is the coordinator, educational designer and teacher of a first year engineering subject. A 'design and build' project is a significant part of the teaching and learning pedagogy. When the first person "I" or "my" is used, it refers to the first named author. This paper reflects my interest in understanding the motivational aspects of the design and build project and students' perceptions of these. It does so within the frameworks of expectancy-value theory (EVT) [1, 2] and self-determination theory (SDT) [3-5]. There are, of course, many theoretical frameworks for understanding/explaining motivation and this paper is not intended to be a review or critique of those. The two theories used were chosen simply because they were the first encountered and explored as part of my professional development and reflective practice. The co-author is a practicing psychologist with whom I have discussed ideas, understandings and findings of this study and who has contributed to the writing of this paper (Disclaimer: the author and co-author are related).

1.2 The general educational background and context

Hands-on 'design and build' projects have for many years been advocated and reported to be essential components of practice-based learning for engineering students [6-9]. For example, Otto and Wood [8] stated that *"It is unrealistic to expect students to design a smoothly operating, profitable machine if they have yet to nail two boards together*" and Silva et al [9] that *"…the virtual mockup does not enable the kind of engineering learning that the physical prototypes convey about interfaces, manufacturing parameters, tolerancing and surface roughness, assembly sequences, etc."*. Indeed this was the main reason that I included a 'design and build' project in the first-year subject Introduction to Mechanical and Mechatronic Engineering. The assertion that design and build projects are also seen to be motivational, e.g. *"Students are extremely motivated by building something palpable with their own hands, which was designed by them from scratch."* [9], became an increasingly important factor in my subject development and in the changes that I implemented in the design and build project and the associated teaching and learning activities. At the same time, my practice had been informed by my developing understanding of theories of motivation. EVT and SDT being the most prominent.

1.3 Expectancy-value theory (EVT)

Wigfield [1] describes the major proponents' perspective of expectancy-value theory as *"individuals' expectancies for success and the value they have for succeeding are important determinants of their motivation to perform different achievement tasks"*. My first exposure to expectancy-value theory was in a teaching and learning workshop on active and collaborative learning where the evidenced-based teaching work of Petty [10] was referenced. I understood from Petty that the level of motivation that a student will have for a given learning task/activity will depend on the extent to which they expect to be able to succeed with the task, and, on the value they ascribe to the task/activity. Further, that the two factors are multiplicative as shown in Figure 1. That is, even if a student highly values the learning, they are less likely to be motivated to attempt the learning if they do not expect to be able to succeed. Conversely, a student may have high expectations of success, but if they do not value the learning activity, they are unlikely to be motivated to perform well with it. Eccles and Wigfield [2] relate “perception of competence” and “perception of difficulty” with “expectancy”, and “individuals’ goals” with “value”. The relationship between expectancy and perception of competence links to the self-determination theory of motivation.

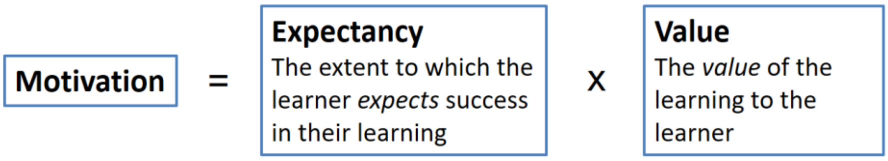

Fig. 1. Illustration of EVT

1.4 Self-determination theory

My understanding of motivation within the SDT framework has been informed mostly by the work of Deci and Ryan [3-5]. They distinguish between intrinsic and extrinsic types of motivation and propose that conditions that support an individual’s experience of autonomy, competence and relatedness foster the most volitional and highest quality motivation and engagement as shown in flow diagram shown in Figure 2. I find it helpful to think of this flow chart in reverse. I want to see in my students, enhanced performance, persistence and creativity, but how do I achieve this? SDT posits that this may be achieved by fostering student volition, motivation and engagement. Yet, how do I foster this? SDT further offers the methods of providing/facilitating student experiences of autonomy, competence and relatedness. Often, as engineering educators, we can tend to focus too much on competence and on our own view of what competence means or looks like. Certainly, I have tended to do this.

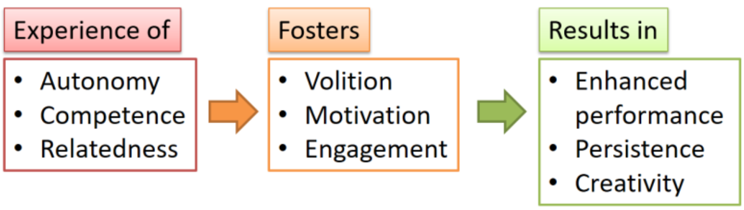

Fig. 2. Illustration of SDT

1.5 Subject and ‘design and build’ project details

The subject Introduction to Mechanical and Mechatronic Engineering is a compulsory first year subject for students in the three mechanical and mechatronic engineering programs at the University of Technology Sydney. Students in other engineering majors (e.g. civil, electrical and biomedical) and other faculties (e.g. Science) may take the subject as an elective at any stage in their degree. Typically, these students make up approximately 10% of the cohort. The intended subject learning outcomes were that upon successful completion of the subject students should be able to:

1. Communicate details of simple mechanical components and devices by using basic skills in freehand sketching, with drawing instruments and CAD solid modelling software to create engineering drawings.
2. Create computer models of simple mechanical components and devices using basic skills in CAD solid modelling software.
3. Apply methods of engineering mechanics to solve problems and analyse relatively simple machine, mechanism and structural components.
4. Apply an engineering design process to evaluate and use components common in mechanical engineering devices to design and build a mechanical device.
5. Apply knowledge of basic mechatronics to construct a simple mechatronic system, incorporate it in a mechanical device and evaluate its performance.
6. Document and communicate their design ideas, decisions, justifications, calculations and outcomes.

The subject was taught in blended mode with aspects of flipped-learning, project-based learning (PBL), inquiry-based learning (IBL) and studio-based learning (SBL). The project, to 'design and build' a wind-powered vehicle (WPV) that uses only the 'power' in the wind to travel into the wind, was the same for all three sessions that this paper reports on. The project incorporated all six learning outcomes. Students worked on the project in groups of 4 or 5. The project was design-oriented, open-ended, challenging and allowed for students to follow their own inquiry-based investigation/experimentation in whatever area most interested them. For example, some students focussed on fluids and aerodynamics and design and tested turbine variations while others focussed on gearing and power transmission. Part of the assessment (15% of the subject total) was based on the performance of the WPV. Having used the same or very similar project scenario for several years, I was confident that I could set an achievable performance benchmark to which I could allocate almost full marks. Students could achieve 14/15 by meeting the performance benchmark. The remaining 1% of the marks were allocated to performance relative to the best performing vehicle, which was awarded the full 15%. In previous sessions all, or at least half, of the marks were allocated to relative performance with only the best performing WPV achieving full marks and lesser performing vehicles achieving a scaled mark.

Having taught the subject for many years, I suspected that a significant, and increasing, portion of the student cohort had very little experience using workshop tools and in making and/or repairing physical things. Therefore, a program of guided instruction in how to use workshop tools was designed around the fabrication of a 'standard' turbine that I knew would perform well and that if the students' vehicle did not work it wouldn't be because of the turbine design. Students were, however, free to choose to modify this turbine or make alternative turbines if they wanted. This program of instruction also served the purpose of introducing students to reading and following engineering drawings and provided them with exemplars for their own detail drawings.

2 METHODS

2.1 Data collection overview and rationale

The survey questions presented here were not deliberately designed as part of a planned research study on students' motivation. Rather, they were my attempt at the time to better understand student perceptions of the impact that the WPV project was having on their development as student engineers. I have always played a very prominent and active role in the workshop/studio classes and was thus able to observe students' in-class behaviour and to engage in discussions with them. This involvement gave me some insight but the surveys provided quantitative and qualitative data, gathered after ethics approval, enabling further investigation and reflection. At around the same time I began to be interested in theories of motivation and have tried to understand and interpret the survey data in this theoretical framework.

The surveys asked some demographic questions and then asked students to select from several statements the one that best represented their previous workshop experience and to indicate on a Likert Scale the level to which they either agreed or disagreed with several statements about their experience and impact of the WPV project. In order to follow good ethical practice, students were invited to participate in the survey after all assessment tasks had been marked and final marks and grades submitted to the university's administration system. The survey was conducted via SurveyMonkey and invitations with the link to the survey sent via email from the subject's LMS Blackboard site. The approved ethics statement advising students that participation was anonymous, voluntary and that they could withdraw at any time was included in the email and the first page of the survey. Data was collected from three consecutive sessions in which the subject and design and build project was run. There were a total of 652 students in the three sessions (254 in session one, 98 in session two and 300 in session three).

3 RESULTS AND DISCUSSION

3.1 Students' previous workshop experience

To better understand the level of workshop experience students had prior to completing the subject and the WPV project, students were asked to select from five statements the one that best described their past workshop experience. The survey results indicated that my observations and suspicions were largely accurate. About a quarter of the students indicated that they had no, or at best very little, previous experience of using workshop tools to make or repair things. Another 44% of students identified with statements indicating only little experience. Only 18% identified with statement that they had made or repaired lots of things using workshop tools and had followed a drawing when doing so.

3.2 Student perceptions: quantitative data

I gathered students' overall perception and reflection on their involvement in the WPV project by asking them if they agreed/disagreed with two statements about whether they enjoyed the WPV project and whether the project improved their experience of being a student at the University of Technology Sydney. A 5-point Likert scale was used with options strongly agree, agree, neutral/undecided, disagree and strongly disagree. As shown in Figure 3, the majority of students (approximately 80%) indicated that they strongly agreed or agreed, while approximately 8% said that they strongly disagreed or disagreed and the rest were either neutral/undecided or made no response.

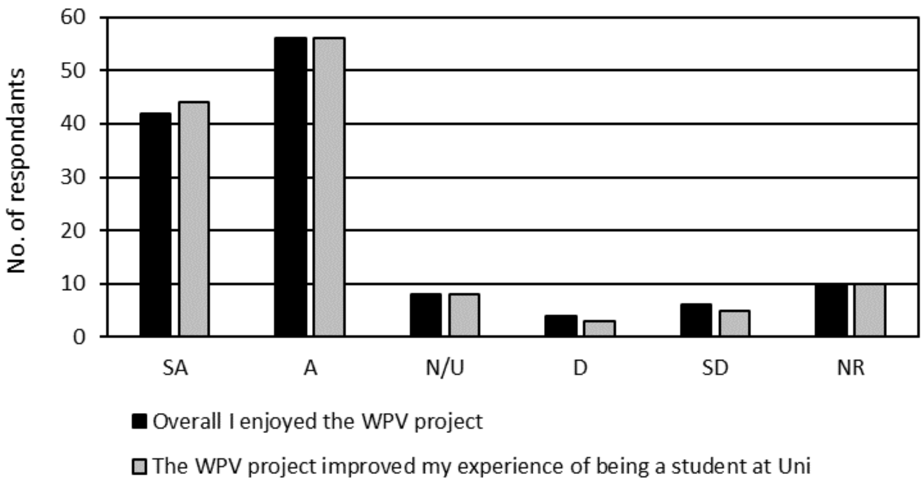

Fig. 3. Quantitative data indicating student overall satisfaction with WPV project.

Students' were asked to reflect on the impact that their participation in the WPV project had on their: Expectation to succeed in their studies; Confidence that they can design a mechanical device; Confidence that they can become a successful engineer; and, Ability to work with other students. A 5-point Likert scale was used with options very positive (VP), positive (P), neutral/undecided (N/U), negative (N) and very negative (VN). As shown in Figure 4, the majority of students (approximately 70%) indicated that the WPV project had very positive or positive impact, while approximately 7% said that it had a very negative or negative impact and the rest were either neutral/undecided or made no response.

I related the first 3 statements to the EVT and SDT motivation factors expectancy and competence and the fourth to expectancy and relatedness. It might also be reasonable to infer that since these students had chosen to do an engineering degree, and specifically a mechanical and/or mechatronic engineering major, that these statements would also relate to their perception of value. Since the majority of students reported a positive experience of all of these factors it may be concluded that the WPV project made a very positive impact on the motivation of the majority of students. A weakness of the study is that I did not ask them a question that related more directly to their perception of value. Also, the students' perception of their experience of autonomy could not be inferred from the survey questions directly. Some indications of students' experience of autonomy were able to be identified in some of the open-ended responses reported in the next section.

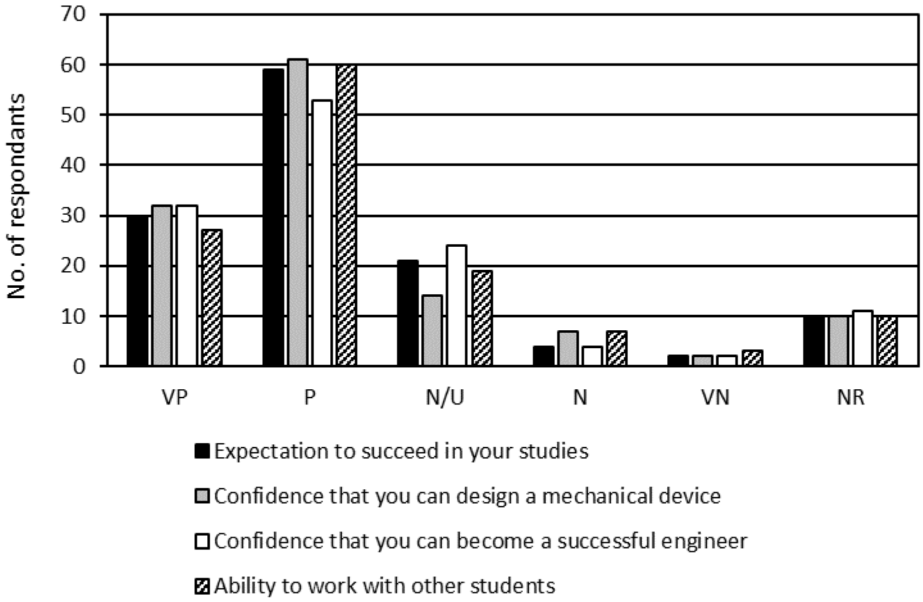

Fig. 4. Quantitative data indicating student perception of WPV project impact on motivation factors.

3.3 Student perceptions: analysis of student statements

Students were asked to provide additional comments to help us to better understand their Likert scale ratings. I arbitrarily selected 24 (of 59) statements that I considered to contain the richest responses and to ensure that responses containing negative statements were selected as the majority of responses were positive. Both authors independently evaluated each statement and indicated if they identified any of the 5 motivational factors (expectancy, value, competence, relatedness, autonomy) by writing E, V, C, R and/or A after the statement. As well, each author indicated whether they thought the statement indicated that the project had a positive or negative impact on each factor by putting + or –. The interpretation and coding of the two authors were in general agreement as shown by the total counts, positive and negative, for each factor (Table 1). Twelve of the 24 statements and the authors' evaluations are included in full in the appendix.

Table 1. Overall coding of student responses

	+E	-E	+V	-V	+C	-C	+R	-R	+A	-A
TB	8	1	8	3	15	2	9	3	2	3
DR	10	2	14	4	18	2	11	4	4	3

It is interesting that DR (a clinical psychologist) identified more factors in the student statements than I did. This may be because neither of us were truly independent. I being the subject coordinator and DR being my relative. Or, it may be due to our different backgrounds and disciplines. There is insufficient data to determine whether the difference is statistically significant.

3.3.1 Student statements relating to EVT

We identified 8-10 statements that indicated that students had an expectation to succeed, for example:

> *"Achieving great results boosted my confidence in engineering studies, mechanical devices, road to becoming a successful engineer and most importantly, working with peers to achieve this result."*

We identified 8-14 statements that indicated that students valued their learning, for example:

> *"The project was really engaging! The mechanics and actual construction especially. It is so much more rewarding seeing how your maths and design go together to create a working vehicle and i feel like i learnt a lot more in those few weeks than i would in the same amount of time sitting through lectures and tutorials."*

According to EVT, this should indicate a positive contribution to student motivation.

We identified 1-2 statements that we believe indicated that the students had an experience that may have resulted in them having lower expectations of success and 3-4 statements that we believe indicated that the students had experiences that may have resulted in possible devaluing of their learning, for example:

> *"in my opinion, the project was hard and this is a type of subject that you just want to give up and focus on the final exam to get a pass/credit grade."*

3.3.2 Student statements relating to SDT

We identified 15-18 statements that indicated students had a positive experience of competence, for example:

> *"overall, this project got me a lot of confidence that I can become a successful engineers. Especially when I was working with my group mates, we all experienced if we plan properly and devide our works right, we can do anything and encourage us all."*

We identified 9-11 statements that indicated students had a positive experience of relatedness, for example:

> *"I learnt that participation to the group is really important, like my small idea or thinking can even change our whole project. we helped each other a lot, not just about this subject, also about our lives as a student at UTS."*

The above quote is one of my favourite. I wish we could achieve this for all students.

These results indicate that the majority of students had experiences of competence and relatedness that contributed positively to their motivation and degree of self-determination.

Only 2-4 statements were identified that indicated students had a positive experience of autonomy. The lower number of statements relating to autonomy is probably because there was no question directly related to this. Below is a particularly noteworthy quote that indicated that the student had a negative experience of autonomy and that this affected the student's motivation:

> *"While I liked the project, the project seemed to steer us towards making a very standard WPV. Indeed it seemed to discourage experimentation with the making of a standard turning*[sic - turbine] *and example vehicle provided. I would have liked to experiment and innovate more"*

This is interesting in that the student perceived a restriction that was not actually there. Students are in fact free to do whatever they want and are encouraged to experiment and innovate. However, in order to help students like the one quoted in the section on student statements relating to EVT who thought the project was too hard, we have provided a 'standard' turbine design that they fabricate as they learn to use workshop tools and an example vehicle on display to help get them started. The students are free to choose whether to continue to use this 'standard' turbine or not.

3.4 'Classroom' observations

It was interesting to see that many groups continued to adjust the parameters of their vehicle (e.g. payload, turbine blade angle) to obtain the best performance from their vehicle that they could even though they'd already achieved at least within 1% of full marks. In discussion with these students it became clear that they saw value in the kudos and/or personal achievement of breaking the record and so were motivated to devote considerable effort to try to achieve the best ever WPV performance. This could be interpreted as evidence that the students had high levels of intrinsic motivation.

4 SUMMARY AND CONCLUSIONS

It is clear that the WPV design and build project has provided the majority of students with positive experiences of competence and relatedness, two of the three components that lead to motivation according to SDT. I expected (hoped) that students would have a positive experience of competence because developing student skills in mechanical design and building functional physical prototypes were primary objectives when I designed the WPV project. With regard to relatedness, fewer students reported positive experience and more students reported negative experiences than for competence. These differences are understandable given the difficulties of group work and differences in personality etc. Despite this it is somewhat surprising (and pleasing) to see how positively many students perceived their experience of relatedness. Teamwork and ability to work with others was not one of the intended SLOs and there was no formal instruction or 'lecture' on teamwork. There was however, deliberate intention and action to support students to work well and collaborate in their groups. This support was provided in the form of mentorship, guidance and assistance by tutors, technical staff and myself. The students' experience of autonomy is less clear. A few students noted particularly that they felt constrained in what they thought they were allowed to do with their WPV design. In fact, they were free to design whatever they wanted within design constraints that were mostly size/safety requirements. In future work I need to focus more on student experience of autonomy, both in evaluating and in designing design and build projects. A difficult challenge is getting the balance right between giving students freedom to follow their own ideas and 'innovations' and to control their own direction and providing support, direction and guidance and not leaving them feeling adrift and thus adversely affecting their experience of competence. Student statements showed how differently students can experience the same learning activity.

The School continues to move to more problem-, project- and studio-based learning throughout the degree [11] and this will likely require students to have higher intrinsic motivation and self-determination. Well-designed and supported 'design and build' projects in first year have the potential to set students on their way to success in new and changing teaching and learning environments and as life-long learners. As inclusion of 'design and build', makerspace and prototyping projects increases in education pedagogy, it is important that educational designers consider students' previous experience in using workshop tools to make things because as seen here, even amongst mechanical and mechatronic engineering students, significant numbers may have little or no experience. This has implications for students' experience of competence and expectancy and hence motivation and self-determination.

REFERENCES

[1] Wigfield, A. (1994), Expectancy-value theory of achievement motivation: A developmental perspective. *Educational Psychology Review*, Vol. 6, No. 1: pp. 49-78.

[2] Eccles, J.S. and A. Wigfield 2002, Motivational Beliefs, Values, and Goals. *Annual Review of Psychology*, Vol. 53, No. 1, pp. 109-132.

[3] Deci, E.L. and R.M. Ryan (1985), Intrinsic motivation and self-determination in human behavior, Plenum, New York, NY.

[4] Ryan, R.M. and E.L. Deci (2000), Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions, *Contemporary Educational Psychology*, Vol. 25, pp. 54-67.

[5] Ryan, R.M. and E.L. Deci (2000), Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. *American Psychologist*, Vol. 55, No. 6, pp. 68-78.

[6] Curry, D.T. (1991), Engineering schools under fire, *Machine Design*. Vol. 63, No. 10, p. 50.

[7] Mourtos, N.J. (2012), Defining, Teaching, and Assessing Engineering Design Skills. *International Journal of Quality Assurance in Engineering and Technology Education*, Vol. 2, No. 1, pp. 14-30.

[8] Otto, K.N. and K.L. Wood (1999), Designing the Design Course Sequence, *Mechanical Engineering-CIME*, Vol. 121, No. 11, pp. 39-42.

[9] Silva, A., M. Fontul, and E. Henriques (2015), Teaching design in the first years of a traditional mechanical engineering degree: methods, issues and future perspectives. *European Journal of Engineering Education*, Vol. 40, No. 1, pp. 1-13.

[10] Petty, G. (2006), Evidence based teaching: a practical approach, Nelson Thornes, Cheltenham.

[11] Hadgraft, R., et al. (2019), Renewing Mechanical and Mechatronics Programs, in AAEE2019, Brisbane, Australia.

APPENDIX - STUDENT STATEMENTS

Both authors independently evaluated each statement and indicated if they identified any of the 5 motivational factors (expectancy, value, competence, relatedness, autonomy) by writing E, V, C, R and/or A after the statement. As well, each author indicated whether they thought the statement indicated that the project had a positive or negative impact on each factor by putting + or –. Our codings are provided below:

1. *"It was a new experience for me to physically build a vehicle from materials with a group. Achieving great results boosted my confidence in engineering studies, mechanical devices, road to becoming a successful engineer and most importantly, working with peers to achieve this result."* – TB, DR: +E, +V, +C, +R

2. *"overall, this project got me a lot of confidence that I can become a successful engineers. Especially when I was working with my group mates, we all experienced if we plan properly and devide our works right, we can do anything and encourage us all."* – TB: +E +V +C +R DR: +E +V +C +R +A

3. *"This project really boosted my confidence in actually designing a vehicle from scratch with various concepts. As we had to buy our own parts and accessories, it thought me how to actually buy products from various hardware stores where I had never been before and the importance for each part (shaft, bearings etc) that contributed the performance of the vehicle."* – TB: +E +C DR: +E +C +A

4. *"The project was really engaging! The mechanics and actual construction especially. It is so much more rewarding seeing how your maths and design go together to create a working*

vehicle and i feel like i learnt a lot more in those few weeks than i would in the same amount of time sitting through lectures and tutorials." – TB, DR: +V +C

5. *"I felt comfortable with the WPV project because it allowed me to design something, build it and see it perform as intended. The project provided me with the opportunity to solve an engineering type of problem and left me feeling confident as a engineering student."* – TB, DR: +E +V +C

6. *"While I liked the project, the project seemed to steer us towards making a very standard WPV. Indeed it seemed to discourage experimentation with the making of a standard turning and example vehicle provided. I would have liked to experiment and innovate more"* – TB: -A DR: -V -A

7. *"By working in a team it showed me how important it was to work in a team where everyone has to participate in order to reach the deadline, therefore relating very closely to a professional situation."* – TB: +V +R DR: +E +C +R

8. *"My lack of initial knowledge regarding workshop tools and how the vehicle would actually work made me feel incredibly out of my depth and unable to visualise how we would create the final product. I am mostly worried that in the future I would be set back by a project whereby I would be expected to know a great deal before participating. This would undoubtedly make me feel stupid or unfit to become a great engineer in the future. Despite this, I learned so much during the project and seeing our final design actually working gave me a sense of accomplishment."* – TB: +C DR: -E +V +C

9. *"Working with my group mates were quite cheerful. It was bit hard to make same time and meet together but we organise and gather all our thoughts, ideas. Then when our ideas becomes real, we were so excited to show everyone. I learnt that participation to the group is really important, like my small idea or thinking can even change our whole project. we helped each other a lot, not just about this subject, also about our lives as a student at UTS."* – TB: +E +V +C +R +A DR: +C +R +A

10. *"My group experience of the wpv was poor. I didn't feel like enough direction was given in terms of how to go about the entire project and found myself and the rest of my team really struggling. It is really a shame because I didn't actually feel like I learnt anything - we just kind of built something that didn't work and we didn't know why"* – TB: -V -C DR: -V -C -R -A

11. *"I enjoyed the project a lot, it was a bit easy though and I'd be more confident in my abilities if it was more difficult or if there was more incentive to make a more complicated WPV. Even though our WPV performed very well I'd have been more proud if it was more inavative but it was more worth while to make a simple vehicle so that's what we as a group ended up doing."* – TB: -V -A DR: +E -V +R

12. *"Very inconsistent teammates (i.e. did not show up, did not contribute) had a negative impact on my experience. However the project itself allows for depth in research and testing while providing sufficient grounding/structure for starting the project, and was enjoyable."* – TB: +C -R DR: +V +C -R