World Transactions on Engineering and Technology Education
Vol.15, No.4, 2017

Cooperative elements in joint projects to enhance first-year engineering students' self-directed learning: a case of a South African university

Marietjie Havenga† & Micheal M. van Wyk‡

North-West University, Potchefstroom, South Africa†
University of South Africa, Pretoria, South Africa‡

ABSTRACT: The aim of this investigation was to explore how cooperative elements could enhance first-year engineering students' self-directed learning in joint projects. A qualitative case study was used as empirical inquiry. The development of a collaborative project is compulsory for all first-year engineering students who are enrolled for the generic course. A cohort of 380 students participated and they worked in collaborative teams. The lecturers identified 64 projects, and a project was allocated to a team, depending on their priority list. Data collection comprised students' written reflective notes and project feedback sheets. Content analysis was used to determine certain patterns of meaning. Teams were selected according to their performance in terms of five cooperative elements, and the way in which these elements contributed to students' self-directed learning. Several positive outcomes and challenges emerged from the plethora of students' views. The results contribute to the body of knowledge on the use of cooperative elements in joint projects to enhance engineering students' self-directed learning and responsible team performance.

INTRODUCTION

Scholars posit self-directed learning as an important process that students should develop to increasingly take responsibility for their learning processes and develop lifelong learning [1][2]. Although the need for self-directed learning (SDL) and its importance are well-documented, studies reporting on the application of teaching and learning strategies, fostering self-directed learning skills are limited, specifically in first-year engineering courses. The most cited scholar of SDL, Knowles coined the approach as: *A process in which individuals take the initiative, with or without the help of others, to diagnose their learning needs, formulate learning goals, identify resources for learning, select and implement learning strategies, and evaluate learning outcomes* [1].

Teaching-learning strategies may support the development of self-directed learning, among others, cooperative learning and problem-based learning. Cooperative learning (CL) refers to students who work together in small groups towards the same goal, sharing the benefits thereof and maximising their own learning and that of their peers [3][4]. Problem-based learning (PBL), as an instructional approach, is based on a question of inquiry and is intended to facilitate the activation of prior knowledge, critical thinking and analysis of arguments, and promotes a deep understanding of the scientific contexts [5]. Moreover, problems used in PBL (ill-structured and complex problems) involve several features that can foster high levels of cognitive engagement and enable students to deeply process the information at hand, which is specifically required from engineering students [5][6].

However, working effectively in teams is a challenge for first-year students [7]. Teamwork does not only involve coming together, but also being responsible, accountable and reliable, and supporting one another in achieving specific aims. The aim of this investigation was to explore how cooperative elements could enhance first-year engineering students' self-directed learning in project development. The research question was: How can cooperative elements enhance first-year engineering students' self-directedness in joint projects?

THEORETICAL OVERVIEW

This section commences with a discussion on self-directed learning, cooperative learning and problem-based projects, as well as the required graduate attributes for the engineering profession.

Self-directed learning

Scholars emphasise self-directed learning by referring to three facets; namely, *self*, *directed* and *learning* [8]. The *self* is regarded as *the* driver *or the manager of the learning process. Directed* involves the purposeful management of one's own learning processes, such as setting goals, making decisions about what and how to learn, and applying appropriate strategies to achieve specific aims. Eventually, *learning* comprises active involvement in processes and practices (e.g. decision-making and reflection) to critically evaluate and use resources, gain knowledge and/or develop a skill [8][9]. Self-directed learning, thus, navigates students' cognitive thinking processes as the *GPS* for developing responsible learning [10].

According to Merriam et al, based on Guglielmino's Delphi survey, a highly self-directed learner has the following characteristics: exhibits initiative, independence and persistence in learning; accepts responsibility for his or her own learning and views problems as challenges rather than hindrances; is self-disciplined and has a high degree of curiosity; is eager to learn and self-confident; able to use essential study skills, manage his or her own time; set an appropriate pace for learning; develops a plan for completing work; enjoys learning; and is goal-oriented [11]. However, it takes time to develop into a self-directed learner.

To expand on this view, Thornton mentions …*that students who realise their own limitations and choose to seek guidance are nonetheless being self-directed* [12]. Other scholars concur with Thornton that to achieve the desired outcomes, students must be provided with learning opportunities to work together, support one another and employ suitable learning strategies to become self-directed learners as pinnacle pillars of SDL [13].

Cooperative Learning

Cooperative learning is formally outlined as an instructional approach that includes the following five essential elements: positive interdependence (the success of the group is dependent on the success of each group member), individual and group accountability, promotive face-to-face interaction (supporting one another's learning), personal interaction and communication, and group processing (reflecting on each member's contribution to the group and celebrating group success) [3].

Johnson and Johnson in their seminal work, *Cooperation in the Classroom*, posit that CL, as pedagogical strategy, enhances active participation and working together collectively towards a specific goal [14]. They distinguish four types of groups [3]. A pseudogroup (members need to work together, but they are not interested in doing so); a traditional working group (members accept working together; however, they belief that they will be evaluated as individuals); an effective group (members commit themselves to maximise their success and that of the other team members); and a high-performance group (an effective group that *outperforms all reasonable expectations given its membership* with regard to the level of commitment to one another).

Artut concurs that in order for a group activity to be cooperative, it is vital that each member aims to increase his or her learning and that of the group members at a maximum level [4]. Furthermore, each member should know which activities he or she is individually responsible for [4]. In line with the views of the scholars of CL, Nelson argues that …*extensive structuring of the learning tasks; strongly interactive student-student execution of the tasks; immediate debriefing or other assessments to provide the teacher and students with prompt feedback about the success of the intended learning; and, importantly, instructional modifications by the teacher that take account of this feedback* [15].

Problem-based Projects

Since collaboration is an important part of real-life experiences [16], applying cooperative elements may scaffold students in project development, since they bring along a variety of skills, responsibilities and experiences during teamwork. Problem-based learning (PBL) as student-centred pedagogy aims to solve ill-structured and real-life problems, particularly in the field of engineering. This strategy provides opportunities for developing 21st Century skills and attributes involving knowledge acquisition, team work, critical thinking and decision-making, among others. According to Savery, PBL can be organised around the development of joint projects and cases, as employed in this research [17].

Graduate Attributes for the Engineering Profession

Graduate attributes, as adopted by the Washington Accord signatories, are categorised according to the knowledge and skills they should demonstrate and the attitudes they should possess in the engineering profession [18]. The pivotal notion is the ability to solve complex engineering problems [18].

The Washington Accord Graduate Profile comprises the following 12 elements engineers need to demonstrate: engineering knowledge, problem analysis, design/development of solutions, investigation, modern tool usage, the engineer and society, environment and sustainability, ethics, individual and teamwork, communication, project management and finance, and life-long learning. In particular, individual and teamwork (WA9) concerns *effective functioning as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings;* and life-long learning involves: *recognising the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change* (WA12) [18]. In response to this note, scholars mention in their 2020 vision regarding the preparation of future engineers that …*engineering programs should introduce hands-on design work in students' first-year and continue it throughout the undergraduate program* [19].

Professional skills involving the elements of the graduate profile should thus be part of such an effort. Case and Marshall concur that graduates have a *particular way of knowing*, which involves the ability to tackle problems with confidence, thinking systematically; working independently and responsibly; and being able to construct knowledge [20]. Since engineering problems are ill-structured and may be solved in various ways, most problems require extensive collaboration and effective communication [21].

The aim of this investigation was to explore how cooperative elements could enhance first-year engineering students' self-directed learning in project development. The following section deals with this objective in the empirical research.

EMPIRICAL RESEARCH

Research Method and Context

A case study design method was employed in this research as a qualitative approach of inquiry [22]. Merriam views that a case is a bounded system or entity within a specific context; for example, a programme or a group to understand the phenomenon under study [22]. In view of the latter, the researchers decided to employ a content analysis to investigate how first-year students in engineering understand their experiences in developing collective projects. The students' *lived experiences* throughout the development of the projects was documented to determine a deeper understanding of their teamwork and students' responsibility during project planning, design, development and evaluation.

The development of a collective project was compulsory for all first-year engineering students who enrolled for the generic introductory course. A cohort of 380 engineering students participated in this research at a South African university. More or less six students worked together in teams. The students were selected to participate in a team by using the Enneagram personality test as a typology of nine interrelated personality types to ensure that they would be able to work in diverse teams as a reflection of real-life engineering settings (note that the words *team* and *group* are used interchangeably in this research).

The lecturers identified 64 projects, and a project was allocated to a team depending on their priority list of possible projects. Some examples of the selected projects were a hammer mill to grind maize, a motorbike trailer (axle and base system) and a garden shredder to shred garden refuge to become useful compost material. The lecturers facilitated skills development in introduction to cooperative learning and problem-based projects; how to conduct meetings; do research; design a project (using Solid Works™); learn about safety, security and PPE (personal protective equipment); compile a work breakdown structure (WBS) (project scope) and a Gantt chart (project time); compile a budget (project cost) and how to prepare a document concerning project requirements for approval.

All participants were required to attend workshop sessions with the aim to developing practical skills, such as drilling, welding and grinding. Moreover, the lecturers had formal meetings with each team to discuss their concept design and drawings, as well as their progress and the problems they experienced. After the lecturers had approved a team's budget, project documents and final drawings, they were allowed to purchase the required materials and start developing the project in the workshop. Team members were also required to assess one another on a weekly basis in terms of their responsibility, accountability and contribution to project development. Senior engineering students were mentors and they supported various teams.

On completion of the project, all participating students were requested to write reflective notes (individual) and they completed project feedback sheets (in groups) regarding their experience in project development and team work. Data collection comprised students' individual reflective notes and project feedback sheets, as well as project documentation. The data were manually coded to capture the richness of the team experiences of participants during project development. Content analysis was used to determine certain patterns of meaning. Ethical clearance was obtained from the university to conduct the research. No names or other identifying details of respondents were revealed to ensure confidentiality, and the students completed informed consent to participate.

FINDINGS AND DISCUSSION

This section presents the findings and addresses the research question: How can cooperative elements enhance first-year engineering students' self-directedness in joint projects?

Findings are coherently presented in Table 1 to indicate team members' use (or lack of use) of cooperative elements when developing joint projects. Selected exemplars of some groups (G) are displayed. The teams were selected according to high, medium and low team dynamics in terms of the five cooperative elements as an indication of their responsibility towards project development. The classification is based on the five principles of cooperative learning outlined by Johnson and Johnson [3]. Each cooperative element is presented with a specific symbol; for example, positive interdependence [ID+] and negative interdependence [ID-]. In the first column (Table 1), an average of all members' final marks for project development is shown. Note that the team members did not necessarily receive the same marks for activities involved in all phases of project development, because individual marks were assigned for individual activities. All quotations are provided verbatim and unedited.

With regard to the exemplars in Table 1, cooperative elements were used as *an indication* of the strength of team performance regarding the students' responsibility towards learning [3]. As evident from these examples, team profiles can be compiled to indicate a specific team's performance in joint projects. For example, the profile of Group 24 is [ID+][RA+][PI+][SS+][GP+], whereas the profile of Group 55 is [ID-][RA+][PI-][SS-][GP-], indicating some challenges in their performance regarding individual CL elements. For example, Group 55 was ineffective in terms of their interdependence [ID-], since all members *did only the minimum*. Furthermore, they lacked assistance; and interaction and support from the group was not always satisfactory [PI-]. These members experienced challenges with social skills [SS-], especially in terms of electronic communication, and they could not keep up with the pace of their team and lagged *behind* [GP-]. Group 55 is an example of a pseudo group, since the members were not interested in working together [3]. The final average mark for the group was 51%, which indicated that this team experienced various challenges. In contrary, the profile of Group 24 is an indication of an effective group, since the members maximised their own learning and that of the other members to achieve success in this context [3]. They obtained an average mark of 66%.

Table 1: Selected exemplars of cooperative elements of teamwork during joint project development.

	Interdependence ID+/-	Individual, group responsibility RA+/-	Promotive (face-to-face) interaction PI+/-	Social skills SS+/-	Group processing GP+/-
G5 (77%)	We …making sure that everyone knows what we expect from them. We all took part in creating the Gant chart [ID+]	Member 5 (M5) … his work is late most of the time and does not care for our own deadlines [RA-]	We are encouraging one another to work harder, faster and better every day. We support one another much better now than in the beginning [PI+]	The team communicates well and looks at a problem from a lot of deferent viewpoints [SS+]	…our planning can get better so can everything, but I do not think it is bad and we are working on it [GP-]
G14 (62%)	Own deadlines was a problem that needed to be worked on by the team as it seemed that members did not fully comprehend the extent thereof [ID-]	M5 often used the excuse of needing to study and thus needed to pass on his work to other members … pressure from the team and the need for him to be reliable and timely cleared up the issue [RA+]	The support and assistance that I (M1 - CEO of each team) receive from the other members, help relieve the workload on me [PI+]	The team uses a WhatsApp group where the group can discuss related matters etc. and easily communicate with one another [SS+]	A meeting was held to clarify matters surrounding own deadlines … Planning meetings around the schedules of all members is resolved by planning it as far ahead as possible [GP+]
G24 (66%)	From the moment we got our project the group brought fresh and creative ideas to the table. We got a lot of input through everybody's concept design [ID+]	M2 created concept design, been secretary twice, made the power point, which got us the garden shredder project and helped creating the final designs [RA+]	M1 did an extra part in activity 5 which was going to the mentors … finding out specifically what we did wrong in the previous activity's, so that we can correct it as a team [PI+]	Up to this point we have had no problem with communication and personal interaction [SS+]	So far, we have posted everything in time and we are proceeding at a steady pace [GP+]
G55 (51%)	Our team did not do as much planning in the beginning for the project, we did only the minimum that was required of the planning. We could have done a lot more [ID-]	We all managed to complete this basic design, most of us having the same basic idea in mind. One of our group members did come up with a very thought out concept which will definitely be used in the final design of the project [RA+]	…in the beginning the assistance was up to standard on the activities. Up to recently the assistance from the group was not up to standard. The support from the group is slowly picking up after our concept design meeting [PI-]	Our electronic communication is not up to standard and we need to focus on communicating better electronically [SS-]	Our team's pace on the project development is not completely where it should be, we are at a set pace so as not to fall behind, but we are planning to pick up our pace a little before we begin our construction [GP-]

Although few quotes were selected as examples of a particular team's performance, the researchers investigated the overall performance of a specific group to determine to what extent they applied cooperative elements in their teams during all phases of project development. These profiles could be seen as dynamic patterns of a team's performance and responsibility, since it may change over time. A typical example is Group 5 that initially experienced challenges ([RA-] [GP-]). However, they encouraged *one another to work harder, faster and better every day*. As a result, they obtained an average mark of 77% for their project. Consequently, it is advantageous to compile such profiles, since these profiles may enable teams to assess themselves; identify their strengths and weaknesses and reflect on their performance with the aim to enhance their responsibility in learning. The renewed focus on implementing cooperative elements in joint projects may be associated with students' self-directedness as shown in Table 2. In addition, the emerged quotes were also aligned with some engineering graduate profile elements [18] in this table.

Table 2: Cooperative elements associated with SDL and aligned with some graduate engineering profile elements.

SDL characteristic [11]	Cooperative elements associated with SDL as evident from the empirical research	Empirical research aligned with some graduate profile elements [18]
Responsibility for their own learning	M2 created concept design, been secretary twice, made the power point, which got us the garden shredder project and helps creating the final designs [RA+] (G24)	Design/development of solutions (Washington Accord element 3)
Goal orientation	We …making sure that everyone knows what we expect from them. We all took part in creating the Gant chart [ID+] (G5)	Individual and teamwork (WA9), and Communication (WA10)
High degree of curiosity	From the moment we got our project the group brought fresh and creative ideas to the table. We got a lot of input through everybody's concept design [ID+] (G24)	Problem analysis (WA2) and Design/development of solutions (WA3)
Viewing problems as challenges	A meeting was held to clarify matters surrounding own deadlines … Planning meetings around the schedules of all members is resolved by planning it as far ahead as possible [GP+] (G14)	Project management (WA11)
Initiative, independence and persistence in learning	One of our group members did come up with a very thought out concept, which will definitely be used in the final design of the project [RA+] (G55)	Problem analysis (WA2) and Investigation (WA4)
Self-discipline	We are encouraging one another to work harder, faster and better every day. We support one another much better now than in the beginning [PI+] (G5)	Individual and teamwork (WA9) and Life-long learning (WA12)
Organise time; pace own learning and develop a plan for completing work	So far, we have posted everything in time and we are proceeding at a steady pace [GP+] (G24)	Project management (WA11)
Enjoy learning	Although implicated, a love of learning was not explicitly mentioned in the emerged quotes	–

With reference to Table 2, emerged quotes are exemplars of cooperative elements that are associated with the enhancement of some SDL characteristics. On the other hand, their love of learning was not openly stated. The quotes are also aligned with some engineering graduate profile elements as stated in the Washington Accord [18].

CONCLUSIONS AND FUTURE WORK

In this article, the authors argue that cooperative learning (CL) is a student-centred approach that is appropriate for applying it in a practical engineering course, where team work is involved. It emerged that cooperative elements were used as an indication of the strength of team performance regarding students' responsibility towards learning. Specific dynamic patterns of a team's performance with reference to their profile emerged; however, such profiles may change over time; for example, the members may develop additional group skills. It is advantageous to compile such profiles, since they may enable teams to assess themselves; identify their strengths and weaknesses and reflect on their performance with the aim to enhance their responsibility in learning.

It is evident from the findings that cooperative elements associated with SDL imitate students' views of the first-year course. Nonetheless, the positive sentiments, like the love of learning, were not openly stated. Overall, it was observed that cooperative elements, especially in effective groups, are associated with some characteristics that may contribute to students' development of SDL in joint projects. The authors only selected some examples in terms of high, medium and low team performance in their application of CL elements; therefore, it could not be generalised. In summary, the findings will guide future engineering courses to intentionally embrace cooperative learning elements associated with the SDL approach. This article concludes with suggestions for research in engineering needed to compare similar courses from first to final year engineering.

ACKNOWLEDGEMENTS

The project is funded by the National Research Foundation. The work is based on the research, which is fully supported by the National Research Foundation of South Africa (Grant No: 106017). The opinions, findings and conclusions or recommendations expressed in this publication generated by the NRF-supported research are that of the author(s); and the NRF accepts no liability in this regard. Permission was granted by the university to use the FIAP 172 data for research purposes only.

REFERENCES

1. Knowles, M., *Self-Directed Learning: A Guide for Learners and Teachers*. New York: NY: Association Press (1975).
2. Merriam, S., Caffarella, R. and Baumgartner, L., *Learning in Adulthood*. (3rd Edn), San Francisco, CA: Jossey-Bass (2007).
3. Johnson, D.J. and Johnson, F., *Joining Together Group Theory and Group Skills*. (11th Edn), Essex, England: Pearson (2013).
4. Artut, P.D., Effect of cooperative learning method on prospective teachers' non-routine problem-solving skills and their views about the method. *US-China Educ. Review* A, 6, **4**, 244-254 (2016).
5. Loyens, S.M.M., Jones, S.H., Mikkers, J. and Van Gog, T., Problem-based learning as a facilitator of conceptual change. *Learning and Instruction*, 38, 34-42 (2015).
6. De Graaff, E. and Kolmos, A., Characteristics of problem-based learning. *Inter. J. of Engng. Educ.*, 19, **5**, 657-662 (2005).
7. Hurst, A., Jobidon, E., Prier, A., Khaniyev, T., Rennick, C., Al-Hammoud, R., Hulls, C. and Grove. J.A., Towards a multidisciplinary teamwork training series for undergraduate engineering students: development and assessment of two first-year workshops. *American Society for Engng. Educ. (ASEE's) 123rd Annual Conf. & Exposition*, New Orleans, LA (2016).
8. Van der Walt, H., *The Feasibility of Grafting Self-directed Learning Theory onto Capability Theory*. In: Mentz, E. and Oosthuizen, I. (Eds), Self-directed Learning Research. Cape Town: AOSIS, 1-34 (2016).
9. White, M. and Hawker, S. (Eds), *Oxford Paperback Dictionary & Thesaurus*. Oxford: Oxford University Press, (2009).
10. Havenga, M., Reflective Team Meetings: a Learning Experience for First Year Engineering Students in Joint Projects (unpublished).
11. Merriam, S., Caffarella, R. and Baumgartner, L., *Learning in Adulthood.* (3rd Edn), San Francisco, CA: Jossey-Bass (2007).
12. Thornton, K., Supporting self-directed learning: a framework for teachers. *Language Educ. in Asia*, 1, **1**, 158-170 (2010).
13. Oswald, D., Instructional-design Theory for Fostering Self-directed Learning. An Unpublished Doctor of Philosophy Thesis, Indiana University (2003).
14. Johnson, D. and Johnson, R., Making cooperative learning work. *Theory into Practice*, 38, **2**, 67-73 (2009).
15. Nelson, C., *Want Brighter, Harder Working Students? Change Pedagogies!* In: Mills, B. (Ed), Cooperative Learning in Higher Education. Sterling, Virginia: Stylus, 119-139 (2010).
16. Bagheri, M., Ali, W.Z.W., Abdullah, M.C.B. and Daud, S.M., Effects of project-based learning strategy on self-directed learning skills of educational technology students. *Contemporary Educational Technol.*, 4, **1**, 15-29 (2013).
17. Savery, J.R., *Overview of Problem-Based Learning: Definitions and Distinctions.* In: Walker, A., Leary, H., Hmelo-Silver, C.E. and Ertmer, P.A. (Eds), Essential Readings in Problem-based Learning. Exploring and Extending the Legacy of Howard S. Barrows. Indiana: Purdue University Press, 72-79 (2015).
18. International Engineering Alliance. 25 years of the Washington Accord (2014), 4 May 2017, http://www.ieagreements.org/accords/washington/
19. Lattuca, L.R., Terenzini, P.T., Knight, D.B. and Ro, H.K., 2020 Vision: Progress in Preparing the Engineer of the Future. (2014), 28 October 2017, https://deepblue.lib.umich.edu/handle/2027.42/107462
20. Case, J.M. and Marshall, D., Bringing together knowledge and capabilities: a case study of engineering graduates. *Higher Educ.*, 71, 819-833 (2016).
21. Jonassen, D., Strobel, J. and Lee, C.B., Everyday problem solving in engineering: lessons for engineering educators. *J. of Engng. Educ.*, 95, **2**, 139-151 (2006).
22. Yazan, B., Three approaches to case study methods in education: Yin, Merriam, and Stake. *The Qualitative Report*, 20, **2**, 134-152 (2015).