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Portfolios for the development of self-efficacy in engineering education

Andrew Way, Karin Wolff, Riaan Combrinck & Abraham Van Wyk

Stellenbosch University
Stellenbosch, South Africa

ABSTRACT: Self-efficacy is indirectly instilled in engineering higher education through graduate attributes. The implementation thereof is not yet effective, as the gap between theory and practice persists. This article presents a project which uses a portfolio report concept to aim to instil affective self-efficacy in university civil engineering students. A cognitive, affective and psychomotor learning model was used in conjunction with periods of experiential industry work and a community of practice approach. The project aimed to improve self-confidence, mastery and motivation, and considered academic, application to practise, and structured reflection tasks to reflect on learning experiences. Feedback indicated that the project broadly succeeded in improving self-efficacy. The project facilitated epistemic transitions to higher forms of mastery, and motivated students by highlighting module relevance to their development as civil engineers. Feedback indicated that a clearer measure of growth perception is required. Future projects should directly use student progress towards graduate attribute competence as a means of improving self-efficacy through growth perception.

INTRODUCTION

The higher education graduates of tomorrow face a world that is super-complex [1]. The World Economic Forum reports an increasing need for the development of self-efficacy in graduates to cope with the dynamic and ever-changing needs of industry and society [2]. Higher education is thus tasked with developing graduates who simultaneously possess the necessary cognitive knowledge and psychomotor skills, but who also have affective self-efficacy in the values of self-confidence, professional identity and resilience, as examples. Additionally, studies show that an increasing proportion of the high attrition rates in tertiary education institutions are attributed to non-intellective aspects, i.e. affective, cognitive-affective and systemic aspects [3].

Self-efficacy requirements are typically incorporated into engineering curricula in theory through professional skills related graduate attributes in competence-based standards for engineering education aimed at addressing industry needs. However, research over time has shown that these are not always effectively incorporated, as the gap between theory in academia and application in practice persists [4][5]. While challenging, the education of holistic, self-efficacious engineering graduates can be facilitated using an education model which effectively integrates learning in all three of the cognitive, affective and psychomotor domains [6][7]. These are paralleled in both Barnet's [1] curriculum model for super-complexity through epistemological, ontological and praxis imperatives, as well as the head, heart and hands concept in Brühlmeier [8]. A focus on stimulating the affective (ontological or heart) domain is particularly relevant in engineering education, where cognitive-psychomotor domain stimulation is often favoured over affective [9]. So, the question is, how do we bridge this affective self-efficacy gap in the education of modern-day engineering students?

Bandura defines self-efficacy as a person's belief in their own ability to complete a task or achieve a goal [10]. He further posits that one's perception of self-efficacy can be altered in one of four ways: active mastery experiences, vicarious learning, social persuasion and the self-appraisal of emotive or physiological responses. Several initiatives and strategies have been explored using one or more of these approaches to promote self-efficacy in various forms in higher education students. Smith and Woodworth highlight the usefulness of community projects in improving self-efficacy through facilitating holistic identity formation, which instils confidence in the ability to affect social change in an entrepreneurial and social innovation education context [11]. Tucker and McCarthy made use of experiential, service-learning pedagogy approaches to improve self-efficacy through improving self-confidence in business and management students [12]. Structured reflections are often used in conjunction with service learning as an effective vehicle with which to improve self-efficacy [13]. The successful use of portfolios to increase motivation and self-efficacy in higher education students was reported by Polly et al [14]. Ponton et al [15], and Asfani et al [16] emphasise the need to showcase university module relevance to engineering practice to promote student self-efficacy through motivation and enthusiasm at university. In terms of the systemic aspect of projects, the efficacy of design-based learning projects, which make use of a reflection-redesign-implementation-evaluation cycle to introduce iterative improvements, is emphasised.

This article details a longitudinal, iterative project which makes use of a reflective portfolio in conjunction with periods of experiential learning in industry to increase self-efficacy over a 2-year period, particularly through the development of self-confidence, mastery and motivation. The project draws on successful initiatives from existing literature and uses a holistic cognitive, affective and psychomotor model with a community of practice approach [17], in the context of undergraduate civil engineering students at a higher education institution in the global south (South Africa).

CONTEXT AND CONCEPTUALISATION

This reflective portfolio project (*the portfolio*) forms part of a programme renewal initiative at a leading, research-intensive university in the global south. In this context, there is notable pressure on universities to cater to a diverse range of students, while at the same time, needing to contribute towards the alleviation of the critical shortage of engineers in the local labour market, as well as to equip students with the skills to be able to compete on a global level [18]. The portfolio was initiated in response to industry advisory board feedback following a degree accreditation cycle with the regulatory engineering body in South Africa for the 4-year Bachelor of Engineering programme. The feedback noted concerns about the industry-readiness of engineering graduates, which is also a global concern [5].

Industry stakeholders noted a specific need for greater graduate proficiency in affective professional skills, i.e. self-efficacy. In response to the feedback, a focus group of all civil engineering academic staff at the university was convened to discuss how the concerns could be addressed. Further concerns were raised by the academics themselves, in that students lacked a holistic *big picture* view of civil engineering and module interconnectedness, and that these resulted in the stifling of the development of civil engineering identity, which can further hinder self-efficacy development [19]. Staff also noted a lack of enthusiasm and motivation when students perceived module content as being irrelevant to civil engineering practice. A number of these points of concern are also associated with student attrition, which is particularly poignant in global south, developing country contexts, where engineering degree completion within minimum time is typically below 50% [20]. There is, therefore. notable pressure on academic staff at the university (and globally) to *deliver* holistic, self-efficacious, work-ready graduates.

The portfolio project makes use of well-established pedagogical theory combined with learning initiatives from existing literature which have proven to be successful, and adapts these to the context of a diverse, developing country in the global south. It incorporates the two most effective of Bandura's [10] proposed measures of self-efficacy perception alteration: students were exposed to active mastery and vicarious learning experiences through academic tasks at university and periods of experiential vacation work in the civil engineering industry. It makes use of a holistic learning model, which combines the parallel theories of Bloom [6], Barnett [1] and Brühlmeier [8] and integrates elements from all three of the cognitive (epistemological, head), affective (ontological, heart) and psychomotor (praxis, hands) learning domains through various elements. A typed portfolio report format was used, which documents learning experiences and includes structured reflections on said experiences. The development of the portfolio over a 2-year period used a dialogical, community of practice approach [21], which incorporates the voices and input of the civil engineering industry (initial need), academic staff, as well as the students themselves as stakeholders to iteratively improve the initiative.

PROJECT IMPLEMENTATION METHODOLOGY

Portfolio Report Content

To address the concerns raised by the industry advisory board and the academic staff, the portfolio report concept was collectively created by the academic staff at the end of 2021. The first iteration of the portfolio was implemented at the beginning of the 2022 academic year. The success of the initial implementation was limited, and it was subsequently refined over the next 18 months through feedback from academic staff and students in the form of interviews and focus group discussions. This article specifically considers the July 2023 (second semester) iteration of the portfolio. As part of a 2nd- and 3rd-year vacation training module (one in 2nd year, one in 3rd), students were required to submit a portfolio report, which detailed their learning over the previous year, considering their experiences during university modules, as well as during a period of vacation work in the civil engineering industry. The report required students to choose any five of the previous years' university modules, preferably from different civil engineering disciplines. Students had to consider three elements for each module: an academic task, an application to practise and a structured reflection.

An academic task (assignment, tutorial question, test, etc.) was included in each civil engineering module from 2nd to 4th year. As part of the improvement after a previous iteration, a brief was created for a (geographic) civil engineering project area, detailing how each civil engineering discipline contributed to alleviating the infrastructure problems faced by the society in the area. The academic task in each module refers back to this area as context for the task. In this way, students repeatedly refer back to the same context from the perspective of each civil engineering module (discipline), thereby aiming to develop a perception of the interconnectedness of civil engineering modules and disciplines. For the purposes of the portfolio report, students were required to retrospectively revisit the academic task done during the module and discuss the problem, its context (within the civil engineering project area), theory and proposed solution. Students were given the following prompts as guidelines for the discussion:

- Identify the problem posed by the task and where it fits into the civil engineering project area.
- Describe the theory and methodology used to solve the problem.
- Consider if similar theory/principles have been used in previous modules and how they have been adapted/built upon to be applicable here.
- What simplifications or assumptions were made to make the problem manageable?

The academic task is aimed to create a form of active mastery experience. Through the initial consideration of the task during the module, students are given an opportunity to actively master an element of the module through the assignment, test, etc. Students are given a second opportunity to master the element through the retrospective consideration and discussion of the task, in a low-stakes context which allows students to freely grapple with the task from a conceptual perspective. The application of module theory to solve the problem activates the cognitive and psychomotor domains, while the reflective, retrospective consideration of the task for the report adds an element of affective domain activation.

The application to practice task is used to reflect on the period of vacation work that students undertake in the civil engineering industry as part of the vacation training modules. The primary aim of the task is to make students aware of the relevance of university module content to civil engineering practice, and to thereby garner enthusiasm and motivation towards learning in university modules, as proposed by Ponton et al [15]. Students are encouraged to reflect on the content of each university module and discuss how they experienced its application during their work in industry. The following were given as discussion prompts:

- Consider which elements of the module content (theory, skills, etc.) you encountered during vacation work.
- Describe the circumstances in which you encountered the application of the module content.
- Discuss how your experience of the application of the content was different in practice from theory in the module (idealised assumptions not being valid, different material/geometries, etc.).

Through experiential learning in industry, the intention is to improve student self-efficacy as they are exposed to active mastery experiences through the work that they do, as well as through vicarious learning as they experience the work of others (colleagues, supervisors, etc.). Additionally, exposure to experiential learning in the civil engineering identity is meant to instil a sense of civil engineering identity in students, which can further improve self-efficacy through the development of resilience and confidence. Reflecting on the application of module theory to practical problem solving in experiential learning environments also helps students to make cognitive (epistemic) transitions towards mastery [22]. Using terminology from Bloom's revised taxonomy [7], the transition from the basic stages of cognitive learning (knowledge, comprehension - theory) to higher forms of mastery through application and analysis can be aided by experiential learning. Periods of vacation work in industry can facilitate these transitions, as students consider how module content is applied and adapted to solve non-idealised, real-world civil engineering problems.

Finally, a retrospective structured reflection task had to be carried out for each considered module after completion of the period of vacation work. Students were encouraged to reflect on the content of the module to evaluate how it contributed to a holistic consideration of civil engineering. Specifically, students were to reflect on how the module content fits into the greater scheme of civil engineering by evaluating where the module built onto theory/skills from previous modules (or disciplines) and where the theory/skills may be applied in future modules. The following guideline prompts were given:

- Broadly describe the content of this module: What did you think you were going to learn in this module? What did you actually learn in this module?
- Relate the content from the module to other modules: What civil engineering stream does this module fall into? What methods/skills/theory from previous modules did you use in this module? What methods/skills/theory from this module are you likely to use in future modules?
- How have you grown or understood civil engineering more holistically as a result of this module?

This affective-cognitive section encourages students to place the content of the module within the holistic context of civil engineering, which has several purposes. In one sense, it is designed to help students to view the current module as a *milestone* to gauge their progress on the journey towards graduating (becoming civil engineers). Schunk illustrates how this perception of acceptable progress, in conjunction with the anticipated satisfaction in achieving the end goal, enhances self-efficacy and motivation [23]. Secondly, it illustrates how all modules function as necessary puzzle pieces within the bigger engineering curriculum picture, enabling students to develop competencies to *become* engineers. This highlights module relevance to the end-goal and encourages self-efficacy through enthusiasm and motivation. Finally, reflecting on module completion aims to improve self-efficacy by highlighting student mastery of one piece of the civil engineering puzzle.

Evaluation Methodology

The systemic implementation was designed with a view of enabling effective iterative evaluation. The evaluation of the efficacy of the portfolio project entailed an iterative, continuous improvement approach using mixed methods. In addition to the central civil engineering project brief, a portfolio template was developed to both clarify the portfolio instructions and minimise the administrative workload of the portfolio. The portfolio reports were qualitatively assessed against a rubric which considered various elements of the portfolio tasks and simply distinguished between unsatisfactory, satisfactory or exemplary portfolios.

As part of the community of practice and iterative, design-based learning approach, the collaborating research team drew on three evaluation mechanisms: the assessor's perceptions of the submitted portfolios, a survey to all students who submitted portfolios, and a focus group discussion with a representative sample of ten students. In the survey, students were prompted to evaluate the extent to which they agreed with cognitive, affective and systemic statements regarding how successful the portfolio was at achieving its aims through Likert scales. For the sake of brevity, the statements are shown with the results in Figure 1 in the following section. Students were able to give freely written comments at the end of the survey regarding the statements or to suggest improvements to the portfolio project/system.

FINDINGS AND DISCUSSION

The findings and discussion are presented first through the qualitative-quantitative results from the survey, and then through a general perception of student engagement through the portfolio reports, the freely written student responses to the survey and the focus group discussion.

Qualitative-quantitative Survey Data

The survey posited statements about the portfolio project to the students regarding the systemic implementation (3 statements), and then from an affective-cognitive perspective (4 statements), to gauge the effect that it had at increasing the students' self-efficacy. The survey was completed by 88 students and was completely anonymous. The statements and results are summarised in the Likert scale bars in Figure 1.

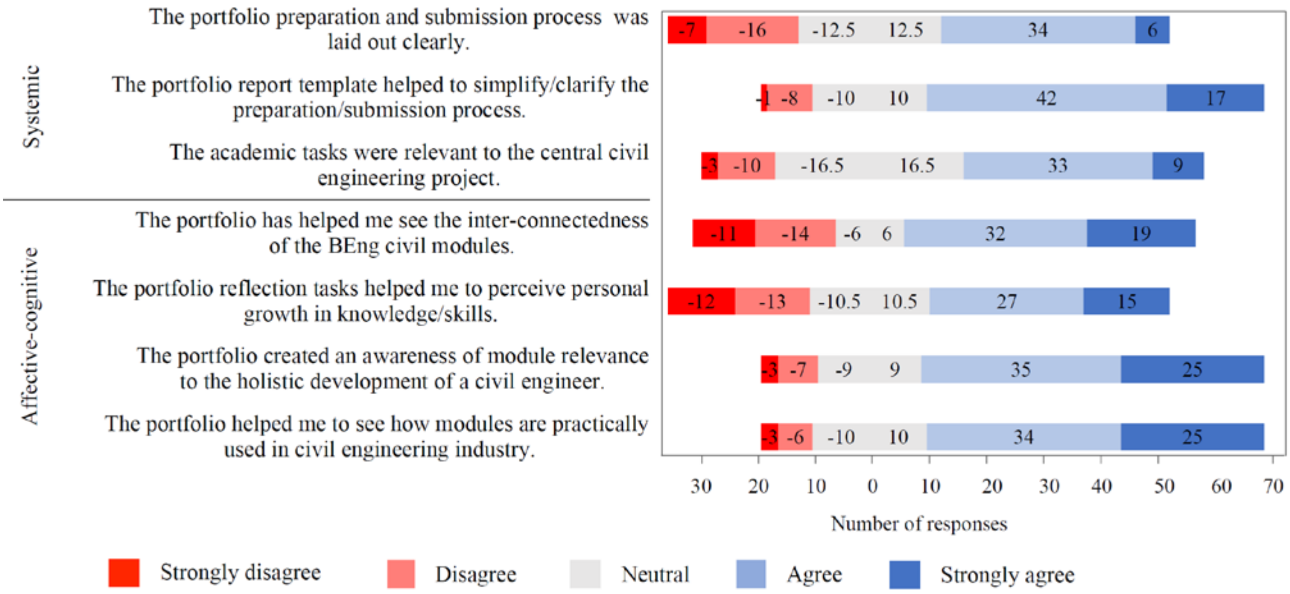

Figure 1: Qualitative-quantitative data from the evaluation survey.

Overall, the student opinion suggests that the portfolio project helped them to improve their self-efficacy. Students generally agreed that the systemic aspects of the portfolio in terms of the preparation and submission process, portfolio report template, and the relevance of the academic tasks were helpful. Of the systemic aspects, the preparation and submission process could be improved, as corroborated by feedback discussed in the following section.

Students also generally agreed with the four affective-cognitive statements relating to how well the portfolio project achieved its four main self-efficacy related aims. The agreement with the final two statements indicates that the portfolio was notably effective at helping students perceive the relevance of university module content to their holistic development as civil engineers, and to the practical use of module content in the civil engineering industry. The portfolio was also successful at highlighting the interconnectedness of the individual civil engineering modules as parts of a greater whole, though to a lesser extent. While still positive, students agreed to the least extent that the portfolio enabled them to perceive personal growth.

Qualitative Feedback

Qualitative feedback was obtained through the assessor's perception of portfolio submissions, free-written responses to the survey and focus group student feedback. From an evaluation of the submitted portfolios, most students meaningfully engaged with the portfolio. Several students showed a critical awareness of their ability to adapt module theory to apply it in practice. With reference to a computer programming-based problem-solving module, one student remarked: *I was responsible for assisting with the programming of macros in Excel* [during vacation work]. *Although macros in Excel use another programming language, I was able to easily adapt and use the knowledge that I gained during the course to solve the problem.* Some students expressly mentioned how the portfolio helped them to perceive their growth, confidence and motivation. Another student noted: *The portfolio is a testament to* [my] *dedication, growth, and readiness to embark on a career in civil engineering. As I look forward to the professional world, I feel that I am being well-equipped to make a meaningful contribution to the field and tackle the complex, multifaceted issues facing society today*.

The freely written feedback and improvement suggestions at the end of the survey helped to get a more holistic picture of the students' response to the portfolio. Student responses corroborated that the vacation work and reflection thereon was helpful in highlighting the relevance of module content. While many students indicated that the portfolio achieved its aims, around 20% of students indicated that the process of repeating the structured reflections for five separate modules was monotonous and that it stifled their willingness to reflect after the first three. A handful of students labelled the portfolio as *yet another academic requirement*. The most common themes that resulted from the improvement suggestions were:

- The repetitiveness and time-consumption of the portfolio process for the modules needs to be reduced.
- The requirements need to be more clearly laid out.
- The workload is too high for the low credit-bearing vacation training module.

The focus group discussion corroborated the sentiments of the rest of the feedback. All students in the group acknowledged the usefulness of the portfolio in achieving its aims and the need to develop self-efficacy, but that the process needs to be more efficient. One student summed up her evaluation of the portfolio initiative succinctly as: *I agree that we need to develop self-efficacy and that the portfolio is a great way to do that, but it would be much more effective if the effort-to-reward ratio was lower*.

The evaluation of the submitted portfolio reports, survey and focus group feedback showed that overall, through integrating academic module tasks, application to practise through vacation work and structured reflections, the portfolio initiative achieved the aim of improving student self-efficacy. From an affective perspective, the portfolio assisted students to reflect on university and industry learning experiences and perceive the part they play in increasing self-confidence and the development of a sense of identity as a civil engineer. Considering the cognitive-psychomotor domain, the portfolio approach of explicitly prompting reflection on the application of university module content in the civil engineering industry was particularly effective at enabling students to perceive the relevance of module content to practise and their holistic development. Furthermore, the application of university theory to industry problems was helpful in facilitating cognitive (epistemic) transitions from lower to higher forms of content mastery.

It appears that the systemic aspects of the portfolio hampered its efficacy. The prompts given for the three tasks were intentionally left open-ended to encourage students to reflect on their personal experiences. From the feedback however, the clarity of the preparation and submission process needs interrogation. While a more prescriptive and less open-ended brief may improve clarity and reduce student frustration, the intention of the entire exercise is to scaffold mastery and deepen overall levels of engagement. As such, in future iterations, a better balance needs to be found between enough prescription to be clear, but not too much to stifle reflection.

Student concerns of repetition and time consumption is likely because structured reflections are not typically inherent in engineering learning, except perhaps near exit-level (final year of study). Linked to this, the perception of growth in knowledge/skills was rated lowest in the affective-cognitive feedback. This feedback seems to indicate that students are not perceiving (or are not being clearly shown) the benefit that the repetition of structured reflections brings in the perception of growth. As such, a better mechanism needs to be implemented as a means by which students can gauge and perceive their progress and growth in competencies toward achieving their aim of graduating. To achieve this, instead of perceiving progress within a single module, future implementations could aim to directly use student progress towards achieving competency in the various graduate attributes as a means by which to measure progress and growth.

CONCLUSIONS

Self-efficacy is an essential attribute that graduates need to navigate the super-complex world of today. While graduate attributes are used to indirectly instil self-efficacy in engineering higher education, the practical implementation thereof into curricula is not yet completely effective, as evidenced by the gap between theory and practice. This research presents a project which aimed to instil affective self-efficacy in university civil engineering students using a portfolio report concept. A holistic learning model which comprised cognitive, affective and psychomotor domain learning was used in conjunction with experiential periods of vacation work in industry and a community of practice approach.

The portfolio project considered academic, application to practise and structured reflection tasks to reflect on learning experiences at university and during vacation work to develop self-efficacy through self-confidence, mastery and motivation. Feedback in the form of the evaluation of the portfolios, a survey and a focus group discussion indicated that the project broadly succeeded in its aims of self-efficacy improvement. It was particularly successful at enabling an epistemic transition from lower to higher forms of mastery, as well as motivating students through the highlighting of university module relevance to industry and each module's contribution towards student development as civil engineers. Systemic elements of the project relating to repetitiveness in the process hampered its effectiveness, in addition to the need for a clearer measure of growth perception towards the final goal of graduation. Future projects could directly use student progress towards competence in graduate attributes as a means of improving self-efficacy through growth perception.

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