Full Paper : Continued exploration of the relevance of self-efficacy, self-determination and agency in describing the first-year African engineering student's experience

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Introduction

Many first-year engineering students at African universities are coming from high schools that rely heavily on rote memorization practices. This can be exacerbated by the challenge of insufficient resources to engage students in more experiential approaches. The dominance of students being directed to read and memorize for tests and examinations has been documented as a common practice in contexts like South Africa [1], but it extends broadly across the continent. The authors see this as potentially leading to negatively affected self-perceptions about students' ability to execute as innovators. If this is the case, the ramifications are significant, as technical skills and innovation are needed for the development and advancement of technology in Africa. According to the World Bank [2], Sub-Saharan African countries currently lack the engineering capacity required for developmental needs especially in areas like manufacturing and infrastructure. It is therefore imperative to better understand how pedagogical practices may impact student self-perceptions towards innovation. As this understanding is formed, best practices can be suggested to foster student problem-solving prowess for economic development.

Ashesi University in Ghana is a small, private institution, which aims to offer a more experiential approach than the norm. The majority of the students are Ghanaians, but 26% are international, coming from 34 countries across Africa [3]. Nearly all come in with similar backgrounds in terms of being traditional college students and also having had minimal exposure to experiential approaches in their prior schooling. Earlier studies amongst this student population indicate that when they engage in project-based learning, their self-efficacy to design and to build increases significantly [4], and this effect is strong enough to manifest even when the project-based approach is offered online [5]. However, it is worth expanding the view of what constructs are most relevant to this set of students. The self-efficacy construct was designed in the Western context, and some argue that it reflects motivation rather than perceived capability [6], motivating a broadened scope of what constructs may be most apt.

Drawing from the author's observations and discussion with colleagues, two other constructs were considered for exploration: agency and self-determination [7]. Agency for learning states that "it is an emergent entity that is manifested in individual abilities to interact with personal, behavioral, environmental and social factors in the learning context" [8]. Learner agency fosters student collaboration, ownership of knowledge conception and overall impact of their learning experiences [9][10][11]. The learner agency of students can be corroborated by actively participating in pedagogical practices that are self-directed and collaborative, like project-based learning [12][13]. Self-determination is the satisfaction of psychological needs for competence, relatedness, and autonomy to form intrinsic and extrinsic motivation [14]. When students engage in project-based learning, their need for autonomy can be met as they actively engage in tasks that promote learning, develop their cognitive capabilities, foster collaboration amongst peers, and when they receive the right scaffolding from faculty [15].

This paper directly builds on a study carried out with the students of Ashesi University who participated in a first-year design-oriented course in 2022 [7]. That study commenced an exploration of the three constructs brought into view – self-efficacy, self-determination and agency, and it revealed the need for relying more on existing validated surveys. Here, a revised

set of scales is used to explore the relevance of these constructs through a first-year engineering course offered at Ashesi University in 2023. This paper seeks to answer: "How relevant are self-determination, agency and self-efficacy in capturing a first-year African engineering students' experience in a project-based course?" and "Does prior participation in a design-oriented course impact the students' experience?"

Methodology

About the course

Introduction to Engineering is a first-year course at Ashesi University, and it is required for all engineering students. It leverages a hands-on, project-based approach to expose students to the basics of the three engineering majors offered: Mechanical, Electrical, and Computer Engineering. The course builds students' skills in design thinking, fabrication, programming, circuit design, etc. It culminates in the design and fabrication of a solution to a prompt provided, which differs in each year's offering. This year's prompt was to design and build a smaller version of a Mars rover, some functionalities of which included avoiding obstacles, moving over rugged terrain, and communicating wirelessly. In teams, they had three weeks to complete eight scaffolded deliverables, culminating in a competition. Each year, this course is offered to two cohorts of about 45 students each. In the 2023 iteration, due to COVID-related delays in high school examination schedules, about half of the incoming students had conducted a "pre-semester" at the University, in which they took various not-for-credit courses. This included Principles of Design (PoD), a course in which students learned design thinking and computer-aided design, which are similar topics to some of what would be covered in Introduction to Engineering. They engaged in design-build challenges, hence they experienced some level of project-based learning as well. Cohort B was comprised only of these students who joined the "pre-semester", hence they had completed PoD. Cohort A, on the other hand, was comprised only of those that were starting their university journey at the time of this offering, hence Introduction to Engineering was the first project-based course they were participating in.

Author positionality

The first author is a Ghanaian, who graduated from the university's engineering program in 2020, and she now conducts engineering education research at the university. The second author is a co-instructor for the course in question. She is an American who has been living in Ghana for a few years, and she is curious to understand how hands-on, project-based approaches may impact her students.

Data collection

A mixed-method approach was used to understand the students' experiences through the Introduction to Engineering course. Pre- and post-surveys were administered to all students- in the first and last weeks of the Spring 2023 semester, respectively. On the pre-survey, questions covered the students' demographic data, experience in designing and building physical items, the location of any previous design-build implementations, and Likert-scale responses for self-reported levels of confidence (self-efficacy) in their ability to design, code, and fabricate solutions, and self-reported levels of self-determination and agency. The post-survey captured the same Likert-scale responses for self-efficacy, self-determination, and agency. It additionally captured open-ended responses on students' experiences working on their final project, dwelling on how they felt about the project from the beginning until completion.

Approval was obtained from the authors' institution's review board with an approval ID 1282023 to conduct research through this project, maintaining student anonymity throughout.

Survey questions

In designing the items used to measure the three constructs in view, existing scales were considered and, in some cases, modified by the authors to better suit the context of first-year African engineering students. The Agency for Learning Questionnaire (AFLQ) tool looks at the behavior of individuals as it applies to functionalities such as intentionality, forethought, self-regulation, and self-efficacy [16]. The AFLQ was modified to suit the context of this study. The original tool contains about forty-two questions on the long form and twenty-eight questions on the short form. In order not to overburden the students, one question from each of the six functionalities under agency was used in the surveys. Thus, questions from intentionality-planned competence, intentionality-decision competence, forethought-intrinsic motivation, forethought–intrinsic motivation, self-regulation, and self-reflectiveness-self-efficacy were selected and modified. Items used for the self-determination scale were adapted from the Basic Psychological Need Satisfaction at Work Scale [17], with three for each of competence, autonomy, and relatedness. Table 1 lists the items deployed for these two constructs in this survey. It captures the modifications that were made to suit the context of this study. For the third construct, self-efficacy, the same items were carried over from the previous study, including "*how confident are you right now to design circuits*", "*how confident are you right now to write programming code*", and "*how confident are you right now to build something using the tools in the workshop?"*

Table 1. Existing Scales vs Modified Scales for Agency and Self-Determination

No.	**Agency (drawn from** [16]**)**	**Modified Agency**	**Self-Determination (drawn from** [17]**)**	**Modified Self-Determination**
1.	I consider how best to carry out a decision.	I consider how best to carry out a decision.	I get along with people at work.	I am motivated to take this course because I can easily get along with people I am placed in a team with.
2.	I feel confident about my ability to make decisions.	I feel confident about my ability to make decisions.	I have been able to learn interesting new skills on my job.	I am motivated to take this course because I like to learn more about engineering.
3.	Because my studies allow me to continue to learn about many things that interest me.	I am studying engineering because my studies allow me to continue to learn about many things that interest me.	I am free to express my ideas and opinions on the job.	I am motivated to take this course because I like to work on something of my choice.
4.	I can rapidly relax myself even when I am in a state of strong internal tension.	I can easily control my emotions even when things are not going so well.		
5.	I can motivate myself to do schoolwork.	I can always motivate myself to do schoolwork.		
6	Because through school, I feel that I can now take responsibilities for changes in my life.	Through engineering, I feel that I can now contribute to solving world problems.		

Changes in self-efficacy, self-determination, and agency

A comparison of the pre- and post-survey results was made on each of the three constructs through a paired t-test analysis. This was repeated for disaggregation across Cohort A (n=24) and Cohort B (n=25) and then across females (n=17) and males (n=32). A Hedges-g test was used to determine the effect sizes of any statistically significant difference. The effect size (g) was considered to be small if $|g| >= 0.2$, medium if $|g| >= 0.5$, and large if $|g| >= 0.8$.

Open-ended questions

At the end of the survey, open-ended prompts were posed to enable the authors to paint a more detailed picture of the students' experiences. Prompts on students' impressions of the course and overall outlook on the final project included: "*State 1 or 2 words that describe how you felt about your project."* and "*Describe your personal experience working on the final project. Did you feel any differently at the beginning and at the end? Did you get discouraged along the way? Which aspects were the most difficult? Which were the most interesting?*". Responses to the former were coded as positive, negative, or neutral. Words like shocked, nervous, stressed, unsure, and doubtful were coded as negative, while words like eager, happy, excited, and determined were coded as positive. In instances where both positive and negative words were used, the response was classified as neutral. The percentage distribution of responses in these categories was captured in disaggregated form across Cohorts A and B. This was done to ascertain whether the students' participation in the earlier course (PoD) may have influenced their experience in this Introduction to Engineering course. Responses to the latter were coded along the three constructs: self-efficacy, self-determination and agency. Words related to resilience, confidence, and planning among a few others were used in coding self-determination, self-efficacy and agency respectively. Thematic analysis elucidated which constructs may have resonated with their experience at any point.

Results

Change in self-efficacy, self-determination, and agency levels

Table 2 shows the results from the paired t-test on the pre-and post-survey administered. Increases in agency and self-efficacy were statistically significant and with small to large effect size. The statistically significant increase in self-efficacy held for both aggregated (all students) and disaggregated data (cohorts A and B). Self-determination began as the highest scoring construct, on average, and it remained relatively high, with no significant increase. These are the same trends that were seen in the authors' preceding work [7], in which the same constructs were investigated but using self-constructed scales and whose loading in the factor analysis was less clean. This suggests that the dynamics at play may be strong enough to persist across imperfect scales. In disaggregated form (across cohorts), the trends remained the same as in aggregate, suggesting that vis-à-vis these constructs, the students had similar experiences regardless of whether they had taken the PoD course earlier or not. Gender disaggregated results revealed the same trends as those seen for the cohort-based disaggregation, which is that for both men and women, self-efficacy increased with statistical significance whilst self-determination and agency did not. Hence no distinction between men and women was observed relative to these constructs.

Table 2. T.test analysis on pre-post construct change in aggregate and disaggregate

			Mean	N	SD	2-tailed sig	|g|
All students	Self-determination	Pre	8.13	49	1.39		
		Post	8.29	49	1.27	4.82E-01	
	Agency	Pre	7.96	49	1.17		
		Post	8.30	49	1.15	4.59E-02*	0.2 (Small)
	Self-efficacy	Pre	4.48	49	2.25		
		Post	7.53	49	1.11	3.96E-03**	1.7 (Large)
Cohort A	Self-determination	Pre	8.03	24	1.55		
		Post	8.15	24	1.33	7.48E-01	
	Agency	Pre	7.98	24	1.21		
		Post	8.43	24	1.07	9.68E-02	
	Self-efficacy	Pre	4.69	24	2.05		
		Post	7.26	24	1.22	8.11E-06***	1.5 (Large)
Cohort B	Self-determination	Pre	8.35	25	1.11		
		Post	8.29	25	1.23	4.33E-01	
	Agency	Pre	7.98	25	1.13		
		Post	8.18	25	1.22	2.72E-01	
	Self-efficacy	Pre	4.27	25	2.46		
		Post	7.79	25	0.96	1.78E-07***	1.9 (Large)

*p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.0001

These results suggest that self-efficacy is indeed likely a relevant construct to capture this student population's key transformation in this first-year course. The course itself appears to have enabled greater self-efficacy to take on design-build projects in the future. The other two constructs in view are likely also relevant, however they may better describe the factors driving them at the beginning of such an experience. The high starting points of self-determination and agency can be interpreted as the students possessing a great readiness to learn and take on the new challenge that the course had in store for them.

Open-ended questions

Results from the question, "*State 1 or 2 words that describe how you felt about your project,*" are shown in Table 3. Cohort B had more students expressing positive emotions around their project experience than Cohort A. This suggests that Cohort B's earlier participation in the course PoD had a positive impact on their experience in Introduction to Engineering, due to having had a higher level of exposure to the content.

Table 3. Distribution of student responses regarding their project experience

Open-ended questions	**Cohort**	**Positive**		**Neutral**		**Negative**	
How did you feel about your project?	A	14	50%	5	18%	7	25%
	B	18	78%	1	4%	4	17%

Four key time-based themes emerged from the coding of the second open-ended prompt. Table 4 presents these themes alongside a sample quote that exemplifies each one. Students tended to describe low self-efficacy at the beginning of this project as it was a new experience, then they described ways in which they leveraged self-determination and agency to persist through challenges during the project, and by the end of the project they described high self-efficacy, having succeeded in completing the challenge. The theme that appeared the most frequently

was the one related to self-determination- many students focused on describing how they persisted through hurdles and setbacks while working on the project and the subsequent changes they noticed about themselves.

Table 4. Select quotes of final project reflections, related to project timepoints

Timepoint	Theme	Quotes of student experience
Beginning	Experiencing low self-efficacy at the start	*"Working on the final project was quite an interesting experience for me. At the beginning, I was unsure about how the project would turn out, which led to a sense of anxiety."*
During	Exhibiting self-determination to carry them through	"*Working in a team can sometimes be challenging, as different personalities and work styles can clash. However, we managed to overcome those hurdles by maintaining open communication and focusing on our common goal."*
	Showing agency to overcome challenges	"*The most difficult aspect of the project was probably the initial planning phase. It required careful consideration of various factors, such as defining objectives, allocating tasks, and setting timelines."*
After	High self-efficacy at the end	"*Overall, it was a great experience, and the biggest thing I have gained from it is confidence, because I have seen myself that it is possible to build… so whenever I think of building something now, I am less scared...*"

Conclusion

A pre-post analysis of 49 first-year engineering students at a Ghanaian university has provided insight into the transformations experienced as they engaged in a project-based course. Of the three constructs in view, self-efficacy stood out clearly as the one that captured a significant increase in the student experience. This held across cohorts and gender. Agency also increased significantly, but with small effect size, and the trend was not observed in disaggregated form. Self-determination started at a relatively high level and remained high. These trends were also seen in a previous study with self-constructed items, suggesting that these dynamics may be strong enough to persist across modification in items in the scales. Studies conducted outside of Ghana have similarly shown project-based learning as a tool that increases student design self-efficacy [18] and that team-related features of project-based learning result in learner agency development [19]. However, a similar result to what was seen here regarding high initial self-determination that persisted has not yet been identified for comparison.

This year's unique offering of having had half of the students participate in a design-oriented course in their "pre-semester" allowed for a natural experiment on the effect of this offering. Although no difference was seen in the pre-post survey analysis, anecdotally the instructors observed greater success in the course for Cohort B, which had participated in the earlier course. This also came out in the qualitative results, where students in Cohort A expressed more negative responses than their counterparts. This suggests that prior exposure to design thinking and project-based approaches positions students to better succeed in a course like Introduction to Engineering. However, regardless of this prior experience, all students grew equally along the three constructs in question. Thematic analysis revealed that generally, students reported beginning with low self-confidence to carry out the project, they faced various challenges along the way, but these taught them to take charge, resulting in growth in mastery of their skills, leading to a high level of confidence by the end. These findings provide insight to better support first-year African engineering students to succeed in their journey. As this population's experience is better understood and articulated, educators and systems can be better positioned to enable them to develop as innovators and problem-solvers. Such solutions hold broad implications for underrepresented student groups globally.

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