An Evaluation of the Effects of Pre-Laboratory Activities on Student Engagement in a Higher Education Computer Engineering Module.

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Abstract.

Improving student engagement, by embracing technologies and adopting student-centred teaching strategies, is one area of educational research. Pre-laboratory activities, supported by technology, have the potential to enhance student engagement, and positively transform practical learning. The aim of this research is to evaluate the effects that pre-laboratory activities have on student engagement with laboratory learning in higher education, in the field of computer engineering. Objectives are: 1) to conduct an analysis of literature on pre-laboratory preparation, as a means to enhance student engagement, and 2) to carry out primary research to determine the effects of pre-laboratory activities on student engagement. The research methodology framework is action research based. Data collection methods employed include student questionnaires, a student focus group, and reflection journals by the lecturer-researcher. Convenience sampling is employed. This study is confined to an introductory electronics module in one former IoT: it does not consider other groups, modules, or higher education institutions. A predominant finding is that pre-laboratory activities have a positive impact on student engagement in areas such as attendance, collaboration, confidence, motivation, and learning. The study concludes that pre-laboratory activities are a worthwhile teaching and learning strategy in a practical module to improve student engagement. One limitation of the study is its small sample size. The key recommendations are to expand the research to a wider cohort and to embed the pre-laboratory activities in the laboratory process from the start, so that students view it as an integral part of their practical work.

Keywords: Action research; Computer engineering; Higher education; Pre-laboratory activities; Student engagement.

1. Introduction.

One goal of higher education institutions is to produce graduates with technical and practical skills. Laboratory-based learning is one teaching and learning strategy that proves effective in equipping learners with these skills. Laboratories are valuable in that they give students the opportunity to work with real data and real instruments. However, the different levels of understanding that each student brings to the laboratory means that a certain portion of students can become disengaged with the challenging content of laboratories (Brinson, 2015; Hofstein & Lunetta, 2004; Ma & Nickerson, 2006). Pre-laboratory activities (PLAs), supported by technologies have the potential to address these challenges and enhance student engagement. In recent decades there has been an increased focus on the adoption of more active, student-centred teaching pedagogies that lead to deeper approaches to learning such as PLAs for practical preparation (Bree, 2018; Dunne & Ryan, 2012; Loveys & Riggs, 2019).

The aim of this research is to evaluate the effects that PLAs have on student engagement with laboratory learning in higher education, in the field of computer engineering. The main objectives are to: 1) to conduct an analysis of literature on PLA preparation, as a means to enhance student engagement, and 2) to carry out primary research to determine the effects of PLAs on student engagement in a selected module. The module in question is an introductory electronics module in the first year of a Bachelor of Engineering degree programme in the field of computer engineering. The paper begins with a literature analysis that focuses in particular on pre-laboratories and student engagement. A discussion on the methodology framework and data gathering methods follows. Findings are then presented followed by a discussion, in dialogue with the literature. The paper concludes with a number of recommendations that emerged from the study.

2. Literature analysis.

This section presents an analysis of the literature, specifically related to PLAs as a means of enhancing student engagement. The first sub-section focuses on student engagement, the second on PLAs, and the third on guidelines for best practice PLA design.

2.1 Student Engagement.

The literature indicated that one of the primary components of effective teaching was student engagement and that engagement was critical for learning (Coates, 2010; O'Flaherty & Phillips, 2015). Student engagement has enjoyed considerable attention in literature since the mid-1990s, with strong roots in Astin's influential work on student involvement (Kuh, 2009). The literature also showed clear links between student engagement and factors like student retention, student satisfaction and academic performance (Fredricks, Blumenfeld & Paris, 2004; Günüç & Kuzu, 2014; Kahu, 2013; Schindler, Burkholder, Morad, & Marsh, 2017; Zepke, 2014).

In this study, student engagement was defined as '*student involvement in the learning process*' (Schindler et al., 2017; Axelson & Flick, 2010). This working definition mirrored the fact that the study did not evaluate the role of external factors, like the campus environment on students' engagement (Coates, 2010; Trowler, 2010; Krause, 2005). While the literature presents a number of models of student engagement, the one adopted in this study was that of Fredricks, Blumenfeld and Paris (2004). They identified types of student engagement which are measurable; behavioural, emotional, and cognitive. Schindler et al. (2017) further developed this typology, referring to 'indicators' of the types of student engagement, as outlined in Table 1.

Table 1: Types and Indicators of Student Engagement (Schindler et al., 2017).

Student Engagement	
Types	**Indicators**
Behavioural	Participation
	Interaction
Emotional	Interests and value
	Sense of belonging
Cognitive	Motivation
	Persistence
	Deep processing of information

This model provided a framework to support the primary research in this study (see section 3.1).

2.2 Pre-Laboratory Activities.

The literature analysis established that the PLAs were beneficial to learning and led to greater student satisfaction and better learning outcomes. Yeung, Cheung and Lin (2021), found that pre-laboratory learning helped students to maximise the benefits of the hands-on practical class. A key recommendation from a study by Dunne and Ryan (2012, p. 14) was the "*absolute need*" to encourage students to prepare for practical sessions. Also, Bree (2018, p.22) stated that implementing PLAs "*in any discipline represents a positive and engaging approach to motivate and focus students, while assisting them to perform better in practical sessions, stimulating learning and understanding overall*". The literature analysis also highlighted that PLAs cannot fully meet the demands of the complex laboratory learning environment (Van De Heyde & Siebrits, 2019). O'Flaherty and Phillips (2015) identified the lack of a conceptual framework to enable a united approach to pre-learning, in-class learning, and post-learning activities as a gap in the literature. Agustian and Seery (2017) addressed this gap by proposing guidelines for designing PLAs, and they noted that most of the studies on PLAs were aligned with discussions on learning in complex environments. They also alluded to the significance of Cognitive Load Theory (CLT) (Agustian and Seery, 2017). Importantly, a key outcome from a study by Seery and Donnelly (2012) found that providing students with preparation resources can help to reduce cognitive load. CLT provides "*a number of instructional design rules for pre-laboratory exercises*" (Jones & Edwards, 2010, p. 2). In this context, they included multiple mode presentations that combine verbal and visual elements and having multiple representations for students to draw on. This idea closely aligns with the principles of Universal Design for Learning (UDL) and constructivism, both of which focus on the diversity of students' learning styles (CAST, 2018; Meyer, Rose, & Gordon, 2014). Further literature supported the premise that students who watched pre-laboratory videos increased their preparedness, found it easy to learn from the videos and their assessment mark increased (Mshayisa & Basitere, 2021; Rodgers et al., 2020).

2.3 Pre-Laboratory Activities Design.

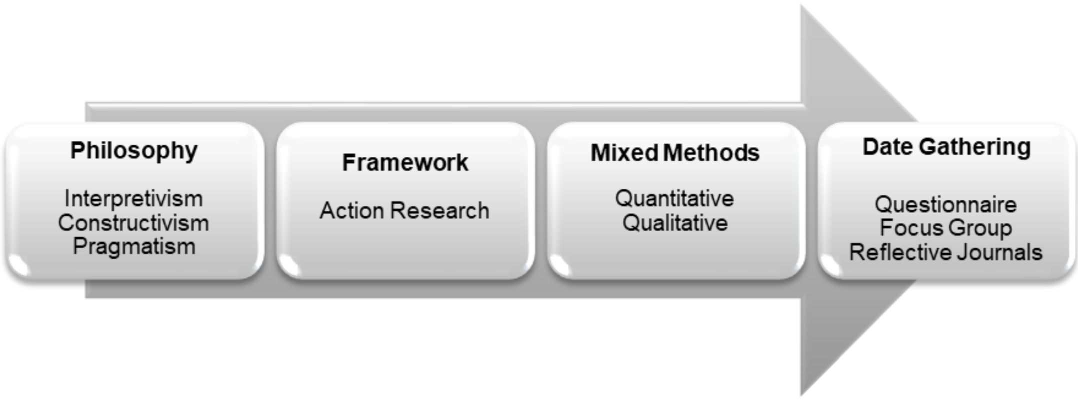
The guidelines and recommendations from the literature analysis were used to underpin the design of the PLAs used in this study (Abdulwahed & Nagy, 2009; Agustian & Seery, 2017; CAST, 2018; Jones & Edwards, 2010; Meyer et. al., 2014; Rodgers et. al., 2020; Van Merriënboer, Kirschner & Kester, 2003). In this design the PLAs incorporated a multimedia video and Tinkercad, an interactive, on-line circuit simulation tool that is freely available (Aasvik, 2018; Reyes, 2018; Tinkercad, 2019). The video and interactive simulator supported diversity in learning approaches. Section 3.1 outlines how the PLAs were used by students.

Having provided a review of the literature, the article will outline and discuss the primary research methodology.

3. Methodology.

An overview of the research methodology chosen is provided in Figure 1.

Figure 1: Research Methodology.

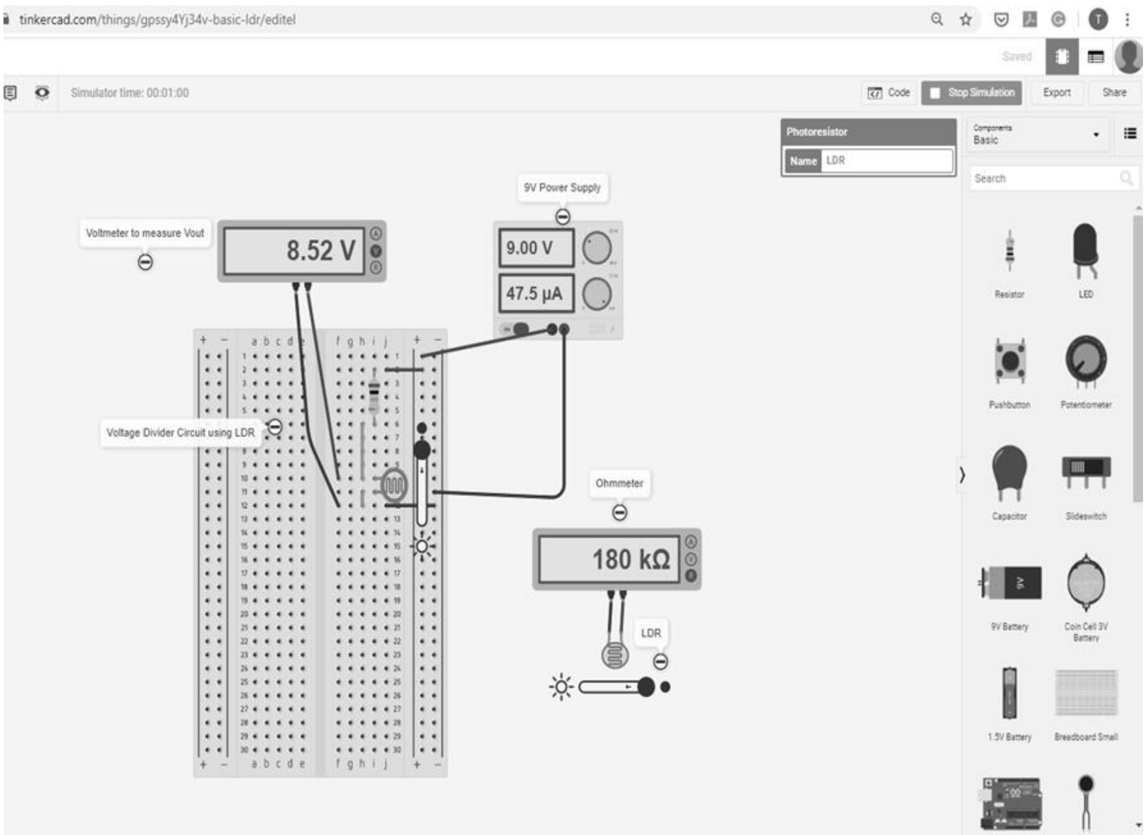


The underpinning philosophies were interpretivism, constructivism and pragmatism. The framework adopted was action research (AR). For the purpose of this study, the AR framework incorporated a mixed methods approach gathering both quantitative and qualitative data was employed. Triangulation was adopted using three data gathering tools; questionnaire, focus group and reflective journals.

3.1 Pre-Laboratory Activities.

Students were requested to watch a video and simulate an electronics circuit, before the hand-on laboratory class. The videos provided guided instructions and explained the underlying theory relevant to the upcoming laboratory thus focusing on supportive material, as recommended by Agustian and Seery (2017). The video addressed the affective domain by using the lecturers own voice and style. With the aid of the video, students were encouraged to use Tinkercad to virtually build the circuit prior to the hands-on practical laboratory. Figure 2 shows a screenshot of a voltage divider circuit, built in Tinkercad. The PLA's resource materials were available on the introductory electronics module Moodle page, making them easily accessible.

Figure 2: A Voltage Divider Circuit - Built in Tinkercad.



3.2 Data Collection.

The data collection methods included a student questionnaire, a student focus group, and lecturer-researcher reflective journals. Schindler et al.'s (2017) conceptual framework for measuring student engagement, shown in Table 1, was used as a basis to inform the design of the data gathering tools. For the purpose of this study, terminological references to '*types*' and '*indicators*' were replaced with '*themes*' and '*sub-themes*' respectively, to align with the thematic analysis approach adopted for the primary research analysis. Table 2 shows how the data gathering methods corresponded to the research objective themes and sub-themes and shows the number of participants (n) for each method.

Table 2: Alignment of the Research Objective Themes with Data Gathering Methods.

			Methods		
Research Objectives	**Research Themes**		**Quantitative & Qualitative Data**	**Qualitative Data**	
Evaluate students' perceptions of their engagement with the PLAs	**Student Engagement**	**Sub-Themes**	**Student Questionnaire (n=24)**	**Student Focus Group (n=5)**	**Lecturer-Researcher Reflection Journal (n=1)**
	Behavioural Engagement	Participation	√	√	√
		Interaction		√	√
	Emotional Engagement	Interest and value	√	√	
		Sense of belonging	√	√	
	Cognitive Engagement	Motivation/ Confidence	√	√	√
		Persistence	√	√	√
		Deep processing of information	√	√	√

The alignment of the data gathering methods and the research themes, and the sub-themes is discussed first, followed by a discussion on participant numbers for each method. As shown in Table 2, the student questionnaire was devised to examine student insights of PLAs and laboratory learning, under three main themes: 1) behavioural engagement 2) emotional engagement and 3) cognitive engagement. All sub-themes were addressed apart from 'interaction' under the behavioural theme. Measuring interaction was deemed to be difficult within the context of a student questionnaire. As a result, this sub-theme was measured using two methods: focus group and lecturer-researcher reflection journals. The focus group method addressed all student engagement themes and sub-themes in the context of PLAs and laboratory learning. With respect to the lecturer-researcher reflection journals, the themes of behavioural engagement and cognitive engagement were examined, including their sub-themes. The emotional engagement theme was not included in the reflection journal process. The reason for this was that the lecturer-researcher was not in a position to determine participants' emotions, without being speculative.

Moving on to the number of participants, at the time of this study, there were 40 students enrolled on this introductory electronics module. These students were randomly split into two groups - 20 in Group A and 20 in Group B. Four students under the age of 18 were not eligible to partake. Of the remaining 36 students, 27 volunteered to partake in this research. The number of participants that completed the questionnaire each week over the 4-week period varied - for attendance reasons. Hence, there was an average of 24 participants with the actual number of participants each week shown in brackets (Lab 4: n=27; Lab 5: n=24; Lab 6: n=24; Lab 7: n=21). The data from the two groups was combined. In addition, approximately 10% of participants left a blank response to a statement in the questionnaire; this is reflected in the data shown in Figure 5, 7 and 8.

Students were invited by email to participate in the focus group. 7 students volunteered - 4 students from Group A and 3 from Group B. Convenience sampling was used, which was appropriate in this case, since a module was being investigated. The focus group was scheduled outside of class time. Only 5 participants attended the focus group - 3 from Group A and 2 from Group B. A decision was made to proceed with the 5 who attended as it would have been unreasonable to expect participants to re-attend at a later time. Literature suggests that the best practice target of focus groups is 6 to 8 participants. In this case, this target was not achieved, which is a limitation of the study. With regard to the third data gathering process - reflective journals - the lecturer-researcher recorded a series of AR reflections over the duration of the study.

A discussion of data gathering follows, in the order of questionnaire, focus group and reflection journals.

3.2.1 Student Questionnaire.

The questionnaire was designed as a mixed methods data gathering tool, incorporating both Likert scale questions and qualitative text questions – see Appendix 1. The questionnaire incorporated 12 questions, split into two sections. The first section contained questions 1-6, which addressed pre-laboratory preparation. These questions included areas such as: identification of PLAs completed, level of enjoyment of PLAs, student perception of the value of PLAs, and students' understanding of theory and skill applications. The second section contained questions 7-12, which addressed the laboratory learning. These questions included areas such as: level of preparation, level of engagement, level of understanding of theory and skills application, and suggestions for improvement, having completed the laboratory. This questionnaire was distributed weekly over a four-week period, with the pre-laboratory questions filled in by the students at the start of the laboratory session and the post-laboratory questions filled in at the end of the laboratory session. With respect to the analysis of the questionnaire data, the quantitative data was represented statistically and a thematic analysis was used to explore qualitative data. Participants' qualitative comments were manually coded according to the sub-themes identified in the literature, but the study was also open to additional themes emerging. Frequency analysis was also used for the weighting of the sub-themes – see Figure 6.

3.2.2 Student Focus Group.

The focus group design was informed by that of the questionnaire, addressing the same themes as shown in Table 2. The data was collected via unstructured and open-ended guiding questions - see Appendix 2. These were divided into five areas of exploration: background of the participants, behavioural, emotional and cognitive engagement with PLAs, and ending with an opportunity to provide further comments. The focus group gave the participants scope to provide a deeper understanding of their experiences using the PLAs and their opinions of them. The group was moderated by the lecturer-researcher. To address the concern that the presence of the lecturer may influence or bias the responses, time was spent articulating to the respondents that the purpose of the group was to get their opinions - both positive and negative. This concern is further addressed in section 3.3. The focus group lasted 1-hour and an audio recording and written notes were taken during the meeting. As with the qualitative data gathered via the questionnaire, manual coding was employed, and thematic analysis built upon the themes and sub-themes previously identified.

3.2.3 Lecturer-Researcher Reflection Journal.

Professional reflection is a central focus of AR (McNiff, 2010; Mertler, 2019; Schön, 2017; Vaccarino, Comrie, Murray, & Sligo, 2007). One of the models of reflection commonly used in education is Gibbs' Reflective Cycle (Gibbs, 1988). Gibbs' Reflective Cycle builds on Kolb's

Experiential Learning Cycle, which is a well-accepted pedagogical model of learning (Kolb, 1984). These models of reflection suggest that theory and practice enrich each other in a never-ending cycle (Finlay, 2008). They also, along with other models, form a basis for AR theory. According to AR theory, "*change does not come about as a result of spontaneous acts, but through reflection on and understanding of specific problems within their social, political, and historical contexts*" (Selener, 1997, p. 105 cited in Vaccarino et.al, 2007). In an AR case study carried out by Costello, Conboy and Donnellan (2015), one of the concerns highlighted was the lack of rigour and guidance on the reflection process. Costello et al. (2015, p.25) designed a structured questionnaire to facilitate reflective practice, and found it to be "*beneficial to his process of learning*", in direct contrast to prior reflection done in an ad hoc manner.

In consideration of these literature findings, a '*reflection journal*' was designed for this study, containing structured questions - see Appendix 3. Adapting Costello et al.'s (2015) model, the journal was structured as follows: description of laboratory environment, feelings and/or reactions, evaluation of student engagement, critical reflection, and an action plan for enhanced practice. The reflective journals captured the lecturer-researcher's observations and insights on student behavioural engagement and cognitive engagement over the four-week data gathering period. The emotional engagement theme was not included, as clarified in section 3.2. The lecturer-researcher employed this data gathering method with groups A and B. In the case of Group A, audio recordings of the reflections were made directly after the laboratory sessions on the homeward commute, and transcribed later. This was to enable the experience and observations to be reflected upon as close to the laboratory session as possible, as per best practice. In contrast, for Group B, the reflective journals were written directly after the laboratory session, since the lecturer-researcher was free at that time. The analysis of the reflection journals built upon the themes and sub-themes previously identified, while also allowing for newly emerging themes.

3.3 Ethical Considerations.

This research was approved by the research ethics committee in the institute within which the research was conducted. One proviso, given the time frame of the study, was that minors would be excluded. Students' informed consent was requested as part of the data gathering process, thereby respecting their autonomy. Participation in the research was voluntary;

participants could withdraw within one month without explanation or fear of penalty. Participants filled in the questionnaires anonymously. All information gathered was kept confidential, with no identifying factors relating to participants included in any reports. All methods and process employed were compliant with General Data Protection Regulation (GDPR). Data was securely stored in electronic form.

The question of power relations emerged as an ethical consideration for this study given the dual role of the researcher as lecturer and researcher. In many AR projects, students are candidates on a course or module being delivered by a lecturer who is also conducting practitioner research on that same course or module. This poses an ethical challenge, as students may feel obliged to participate in the study and/or to respond in a particular way (Gibbs et al., 2017). A concern is that the presence of the researcher may potentially influence and bias the participants' response. Addressing this concern, time was spent articulating to the participants that the goal of the research was to get their opinions of the learning experience in order to improve practice. During this research study, all students were treated equally, and no one benefitted unduly by partaking or was discriminated against if they chose not to participate.

4. Findings from the action research study.

The findings from the AR study are presented thematically, according to the themes of behavioural engagement, emotional engagement, and cognitive engagement, and their respective sub-themes – see Table 2.

4.1 Findings for the Theme of Behavioural Engagement.

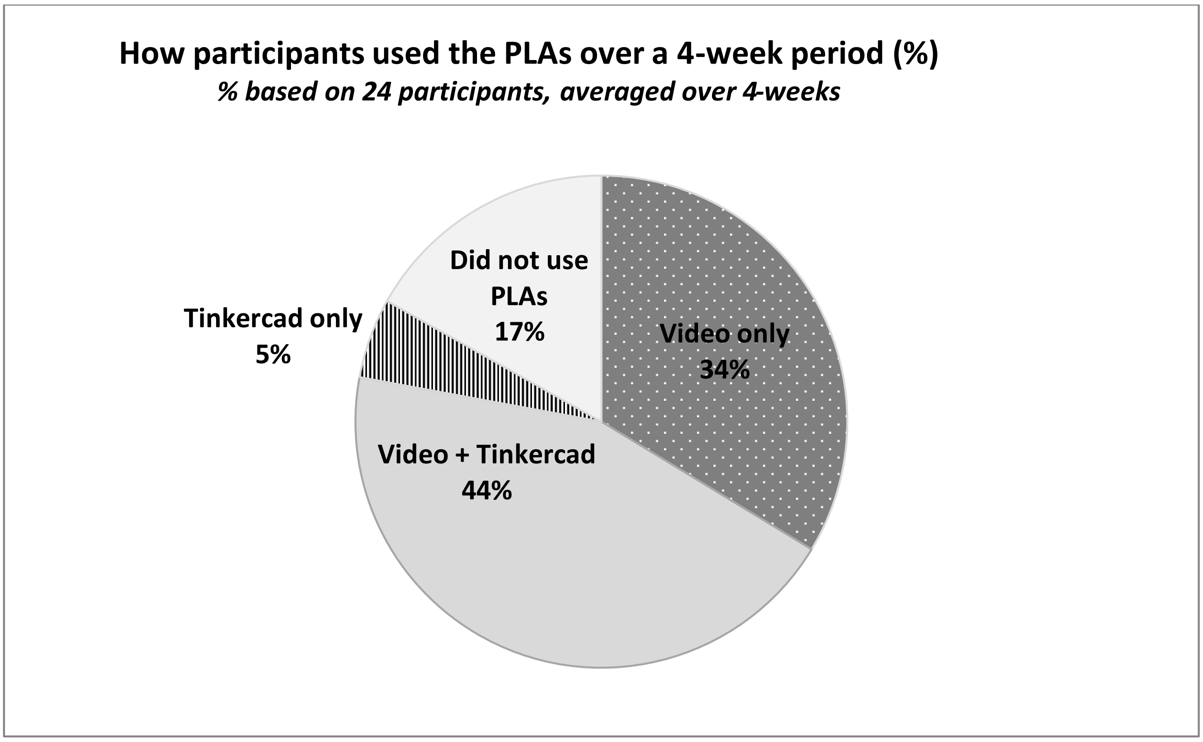
This section considers how the PLAs impacted on students' behavioural engagement with laboratory learning highlighting the sub-themes of '*participation*' and '*interaction*'.

4.1.1 Participation Sub-Theme.

Participation is the action of taking part in something. In this study positive participation was found in the following behaviours: pre-class preparation, attendance, taking an active part in classes, paying attention, asking questions, and making an effort to engage with the learning process. Question 1, in the questionnaire, asked "*how did you prepare for this laboratory?*".

Responses - based on an average of 24 participates questioned over 4-weeks - indicated that there was strong engagement with the PLAs during the four-week research period. As shown in Figure 3, 17% did not engage with PLAs. The remaining 83% was divided between Tinkercad only (5%), videos only (34%) and a combination of video and Tinkercad (44%).

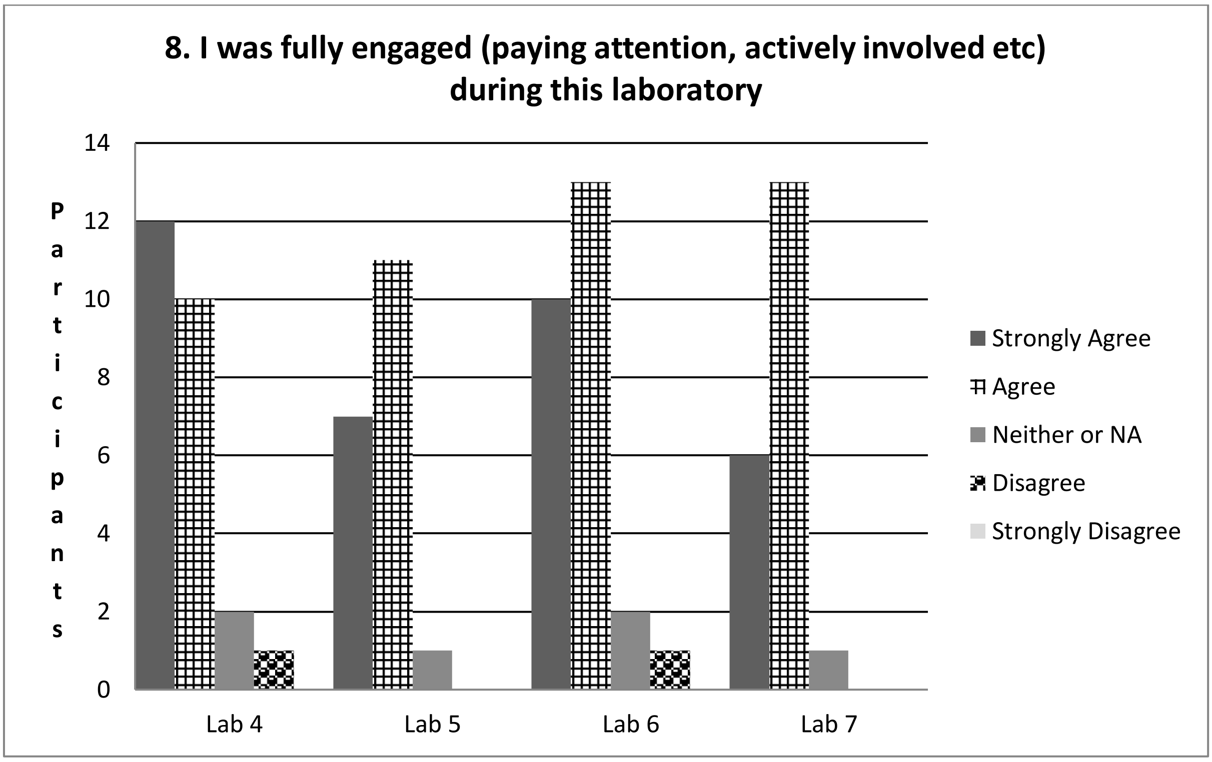
Figure 3. How the Participants used the PLAs over the Four Weeks.



Examining participation from the perspective of engagement, participants' responses to the statement in question 8, namely "*I was fully engaged (paying attention, actively involved etc.) during this laboratory*", indicated that the majority described themselves as engaged (see Figure 4). 36% of participants selected Strongly Agree, 48% Agree, 6% Neither Agree nor Disagree, 2% Disagree, and 0% Strongly Disagree. This trend remained consistent over the four weeks.

For the purpose of clarity, it is important to point out that while these findings showed participant perception of their engagement levels in the laboratory, this finding did not directly link to the PLAs. It will be shown later that other data points and qualitative data were used to understand why students agreed that they were fully engaged, and how that linked to the PLAs.

Figure 4. Responses to Statement 8 over the Four Weeks of Laboratories.



The lecturer-researcher reflection journal entries supported the quantitative finding that students were engaged in the laboratory. The journal entry for Laboratory 4 Group A noted;

> *Good engagement from the students. Good contributions when I posed questions or asked for formulas to solve problems. Good work ethic, everyone getting stuck-in to the task. A lot of students were able to complete the task with little or no help, a few with a little guidance and two students needed a lot of help, but they got there in the end. I felt most students were interested and making efforts in this lab.*

The findings of the interaction sub-theme follow.

4.1.2 Interaction Sub-Theme.

Interaction was understood here as '*communication or direct involvement with someone or something*'. Peer-to-peer, and student-PLA tools interactions were predominant in this study. There was strong evidence of peer-to-peer interaction. This was evidenced in the lecturer-researcher reflection journal, with entries like "*nice group dynamic*" and "*good teamwork"* recorded. Peer-to-peer interactions were also discussed in the focus group. A common point made by the group was that they were more likely to give assistance to their peers in the laboratory, since having done the PLAs, they were more confident in their own knowledge. As described by Participant B, *" . . . if I had my circuit built and measured and someone else was struggling, because I understood, I could turn around and help them*."

In terms of student-PLA tools interaction, Figure 3 illustrates that 5% interacted with Tinkercad only and 44% interacted with both Tinkercad and videos. Nobody used the on-line sharing feature on Tinkercad to share their circuits. The qualitative findings with regard to the interaction with Tinkercad, from the questionnaires and the focus group were analysed. The explanation for the low-level interaction (5%) with '*Tinkercad only'* was that participants' did not feel it was necessary every week, as the video was enough. As noted by one participant: "*The video is always some help. I don't think Tinkercad is needed every week*". Another student observation for the lower interaction with '*Tinkercad only*' was "*if it was a whole semester thing it would become a habit, but since it was only for four weeks, it was hard to get into the swing of it*". This correlated with comments given in the questionnaire that participants "*forgot*" to do Tinkercad. In addition, the PLAs were voluntary, and this may have been a deciding factor for those students who did not use them. Some participants indicated, if they were mandatory or had marks allocated to them, more students would do them.

The following section looks at the findings for participants' emotional engagement with the PLAs and laboratory learning.

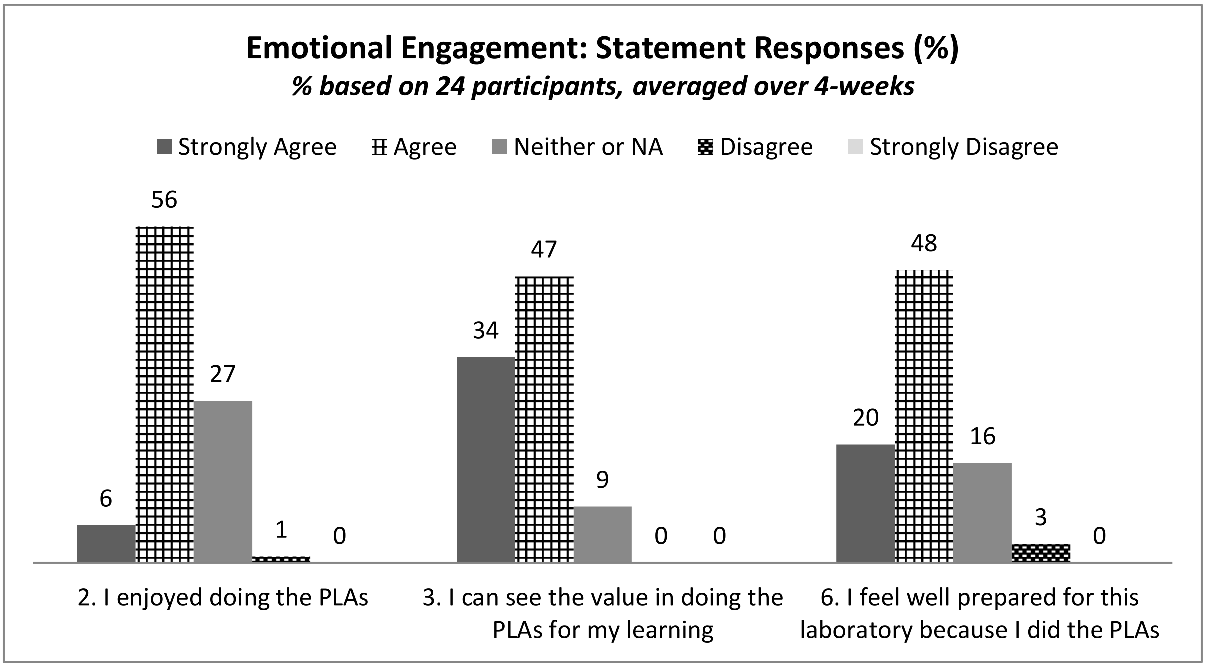
4.2 Findings for the Theme of Emotional Engagement.

The sub themes that emerged from the dominant theme of emotional engagement included '*interest and value*' and '*sense of belonging*' (see Table 2). These sub-themes will be presented in turn.

4.2.1 Interest and Value Sub-Theme.

For the purpose of this study the terms '*interest*' and '*value*' are understood as follows: interest is the feeling of the student, whose attention and curiosity is engaged by the learning, and value relates to the students' perception of a learning experience being useful, relevant and of worth. A summary overview of the participants' quantitative responses to statements included in questions 2, 3 and 6 from the questionnaire can be seen in Figure 5. Question 2 states '*I enjoyed doing the PLAs*', Question 3 states '*I can see the value of doing the PLAs for my learning*', and Question 6 states '*I feel well prepared for this laboratory because I did the PLAs*'.

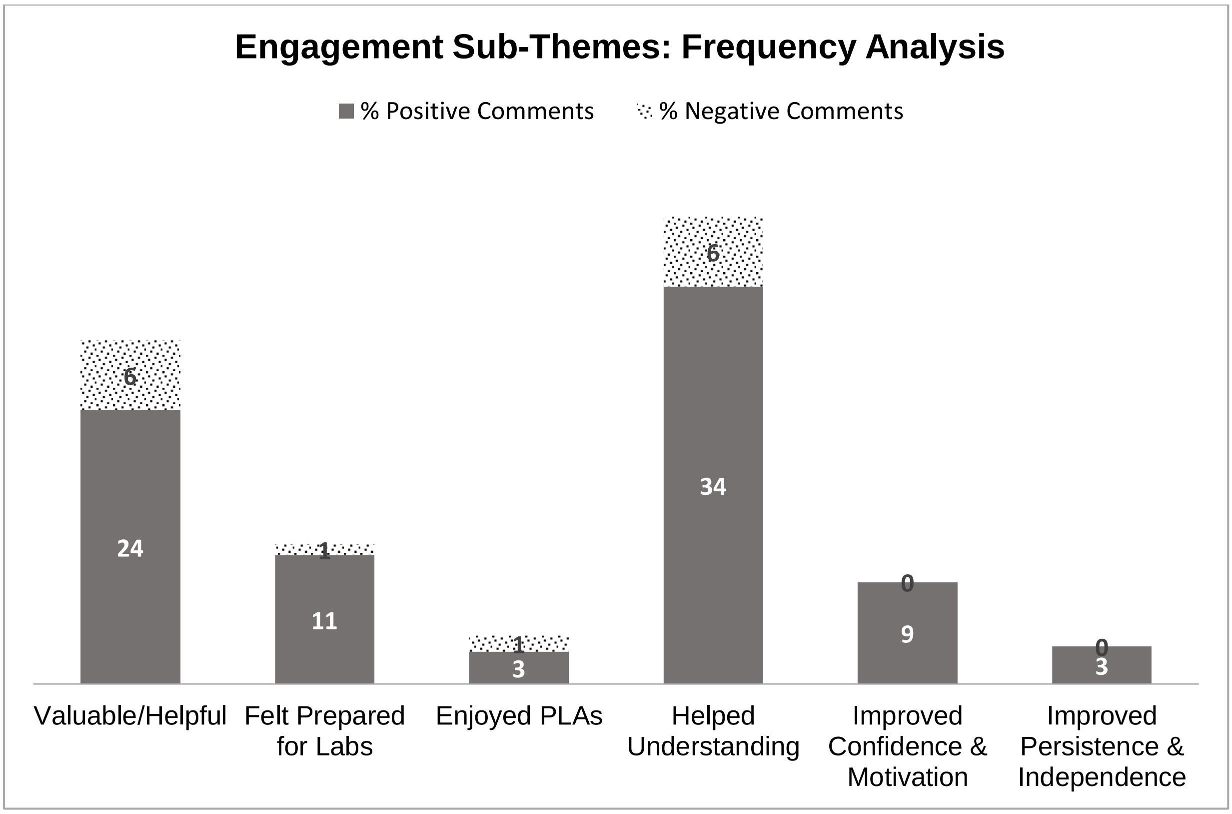
Figure 5. Responses to Statements on Emotional Engagement.



These findings, based on the average of 24 participants, showed that the PLAs impacted positively on students' emotional engagement. For Question 2, 6% selected Strongly Agree and 56% Agree that they enjoyed doing the PLAs. For Question 3, 34% selected Strongly Agree and 47% Agree that they saw value in the PLAs for their learning. Lastly, for Question 6, 20% selected Strongly Agree and 48% Agree that they felt prepared for laboratories as a result of the PLAs.

Qualitative findings from the questionnaire, that explored the value, preparedness and enjoyment of learning students attributed to the PLAs were analysed - see Figure 6. 24% of comments indicated they were valuable/helpful, 11% indicated the PLAs helped them to feel prepared for the laboratory and 3% expressed enjoyment towards the PLAs. Comments included; "*It is very useful to see it done beforehand*", "*Additional preparation helps me understand the topic better*" and "*I found them interesting*". Subsequent discussions as part of the focus group confirmed these findings with participants' agreeing that the PLAs were of value; "*I used the pre-labs again and did well in the skills lab because of that* ", "*were not getting stressed or worried" and "it was informational*". Only 6% of participants disagreed that the PLAs were valuable/helpful. Questionnaire comments included "*It was the same as the notes*", "*I'm not well prepared, have an idea*" and it was "*time consuming*".

Figure 6. Engagement Sub-Themes from the Qualitative Data in the Questionnaires.



4.2.2 Sense of Belonging Sub-Theme.

Within the context of this study the sub-theme '*sense of belonging*' relates to the participants' affinity with the group learning experience. This was evident through indicators such as preparedness, knowing what they are doing and feeling comfortable in the group learning.

Data from the focus group indicated that the participants believed that the PLAs did help them to prepare for the laboratories, and they linked this feeling of preparation to improved confidence in their abilities to carry out the laboratories successfully. Participant C states: "*I am much more confident going in*" and Participant E indicates confidence in their ability to prepare for a skills exam *" . . . know I'm definitely going to be able to do that*". Using the PLAs led to more independent self-directed learning as outline by Participant D: "*I didn't need you holding my hand every time*". Participants suggested being "*well prepared*" and "*knowing what we will be doing*" also helped their sense of belonging in the laboratory. Participants stated the PLAs "*gave me a reason*" to attend class and that they allowed them to "*see the benefit*" of attending class. They also referred to not feeling out of their depth "*like an eejit*" and seeing "*no point*" attending. They also indicated that it prevented them getting "*fed-up*" with the subject. Having presented the findings of behavioural engagement the next sub-section looks at the theme of '*cognitive engagement'*.

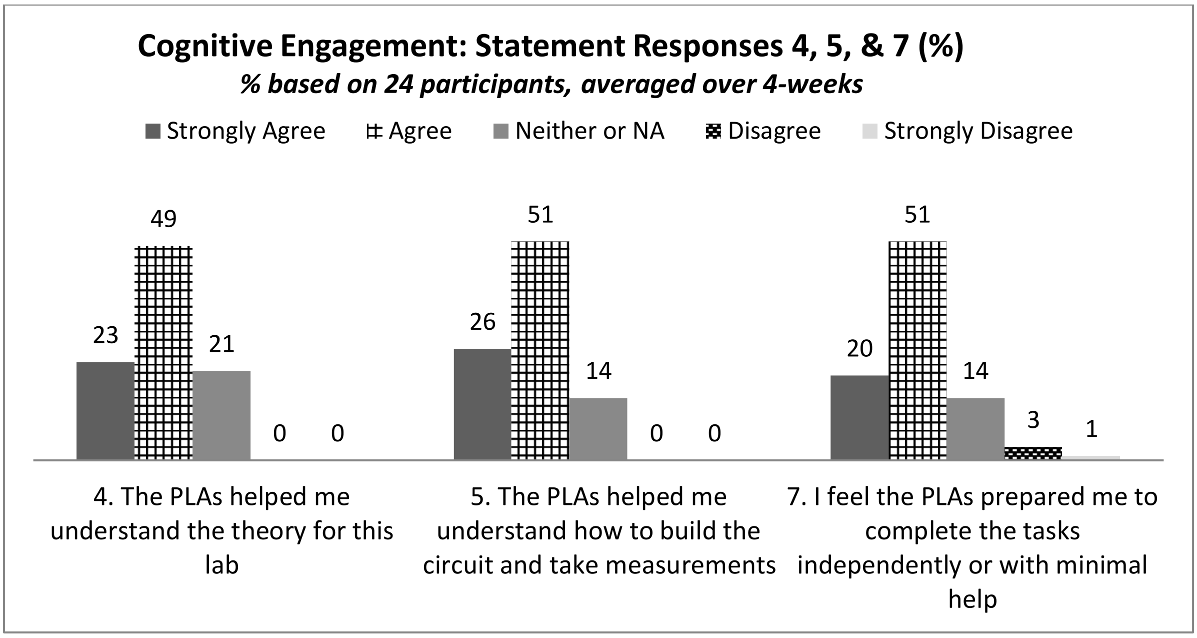
4.3 Findings for the Theme of Cognitive Engagement.

Cognitive engagement is the degree to which students approach learning and expend mental effort to comprehend and master content (Fredricks et al., 2004; Schindler et al., 2017). Sub-themes of cognitive engagement included motivation/confidence to learn, persistence to overcome challenges and deep processing of information through critical thinking, self-regulation and active construction of knowledge (Schindler et al., 2017).

4.3.1 Motivation/Confidence Sub-Theme.

The following data provides information on participants' opinions of how the PLAs helped their learning and motivated them to learn independently. Figure 7 gives a summary overview of the participants' quantitative responses to the statements in questions 4, 5 and 7 from the questionnaire, which addressed the cognitive aspect of the study.

Figure 7. Responses to Statements 4,5 & 7 on Cognitive Engagement.



Question 4 stated '*the PLAs helped me understand the theory for this laboratory*'; based on an average of 24 participants, 23% Strongly Agree, 49% Agree and 21% Neither Agree nor Disagree. No respondents stated that they Disagree or Strongly Disagree. Question 5 states '*the PLAs helped me understand how to build the circuit and take the measurements*', with 26% selecting Strongly Agree, 51% Agree and 14% neither Agree nor Disagree. Again, no respondents stated that they disagreed or strongly disagreed. Question 7 states '*I feel the PLAs prepared me to complete the tasks independently or with minimal help*', with 20% selecting Strongly Agree, 51% Agree, 14% Neither Agree nor Disagree, 3% Disagree and 1% Strongly Disagree.

Qualitative findings from the questionnaire, that indicated improved confidence and motivation to learn, included comments such as "*I am confident going into the lab*"; "*I found making the circuit easy after doing it on Tinkercad*" and "*previous labs I was unsure what to do*". Figure 6 shows that 9% of comments were positively related to improved confidence and motivation. This sub-theme was also discussed in the focus group and all responses indicated a positive impact on participants' confidence and motivation to learn and problem solve. As noted by Participant A *"[The PLAs] motivated me a lot to build circuit . . . but then I was experimenting, what if I put this resistor in, what if I put this capacitor in, what's the effect, what's the result?"*. Participant E states;

> *I just found being able to go into class feeling so confident about your ability and your understanding . . . it gives a very positive mood, you go into class, and you get everything done, you feel good about it, and it encourages you to continue doing the PLAs and to continue learning.*

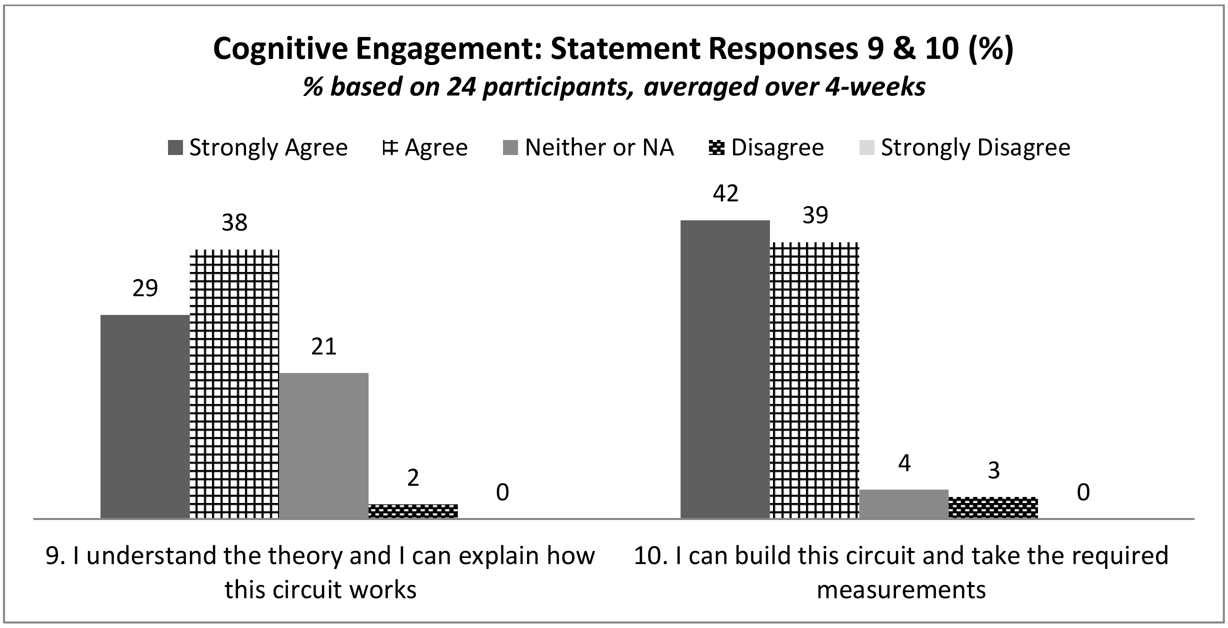
The Laboratory 6 lecture-researcher reflection journal, based on student observation, confirmed that the students "*had a good understanding of how to build the circuit*".

The next sub-theme explores persistence.

4.3.2 Persistence Sub-Theme.

In this study persistence is understood as the continuation of learning, despite difficulty. Questions 9 and 10 provided information on participants' persistence in understanding the necessary theory and then apply it in the laboratory after using the PLAs. Figure 8 gives a summary overview of the participants' quantitative responses. Question 9 states '*I understand the theory and can explain how this circuit works'*: 29% selected Strongly Agree, 38% Agree and 21% Neither Agree nor Disagree, 2% Disagree, and 0% Strongly Disagree. Question 10 states 'I can build the circuit and take the required measurements' with 42% selecting Strongly Agree, 39% Agree and 4% Neither Agree nor Disagree, 3% Disagree, and 0% Strongly Disagree.

Figure 8. Responses to Statements 9 & 10 on Cognitive Engagement.



Data from the focus group confirmed that persistent learning activities were exhibited by the participants. The ability to do the PLAs in their own time and to pause or re-watch the videos was noted as important for their learning. Participant D states that *"(y)ou can re-watch the videos so if you don't understand it on the first run, you can do it again and again until you get a better view*." Having key content readily available assisted the participants to persist in their learning journey. Participant E notes that; "*with the videos and your Tinkercad circuits being saved on-line and easily accessible . . . it means all the information you need is very easily findable; you know where to go for the exact information you need*". The Laboratory 5 lecturer-researcher reflection journal supported the above findings; *"(a)ll students were making good efforts. 1 group (where a student was absent the previous week) . . . was struggling to catch up . . . really persevered in their attempt to measure the current*."

The next sub-theme explores deep processing of information.

4.3.3 Deep Processing of Information Sub-Theme.

In this study, the '*deep processing of information*' refers to the capacity to demonstrate higher order thinking, critical reflection, understanding and application of knowledge to new contexts. Qualitative findings from the questionnaires demonstrated these qualities. As shown in Figure 6, 34% of comments indicated that the PLAs helped understanding. Examples of the comments given are highlighted here: "*I could pause, reverse and understand everything slowly*"; "*I found visual in Tinkercad much better than reading the theory*"; "*good revision tool*" and "*it built on what I had learned in lectures*". Data from the focus group also indicated that participants found the PLAs helped their understanding. Participant D attributed the direct link between theory and practice as a significant aid to their learning: "*linking the theory to the circuit makes it easier to understand*". Participant A and C suggested that being able to "*experiment in Tinkercad*" led to improved learning and contributed to an enhanced understanding of theory. Participant D indicated that the PLAs helped them to acquire a deep understanding of the content:

> *I find if you are going into something blind [the lab], you will barely scrape through it without understanding it at all, you're not going to remember it the next day. If you have done the PLAs, you will know what you have done, and you can do it again if someone asks you.*

Data from the lecturer-researcher reflection journals indicated that a good portion of students have a good understanding of the underlying theory. It was noted in the reflective journal for Laboratory 5 that *"(i)Interaction levels were very good. Students were asking very relevant questions. It seemed a lot of the students had a good grasp of the key understandings and concepts required*."

There were some indications of challenges. For example, in the questionnaire, a small number of participants stated that they were found the deep processing of information difficult: "*I found it hard to follow*"; "*I struggled to grasp the theory*", and "*I just found it hard to explain how it works*". Figure 6 shows that 6% of comments were categorised as negative towards the PLAs being helpful to understanding. An excerpt from the reflective journal for Laboratory 6, mirrored this concern;

> *I feel the engagement with the PLAs was poorer this week and that some students were not familiar with or did not understand the theory they needed to know. About half the students didn't seem to be very comfortable using the formulas.*

Having presented the research findings relating to behavioural, emotional, and cognitive engagement with the PLAs the next section will discuss these findings.

5. Research Discussion.

The discussion will address each theme in turn, examining the implications of the findings in dialogue with the literature.

5.1 Discussion on the themes.

Under the theme of behavioural engagement, the sub-themes were '*participation*' and '*interaction*'. Beginning with participation as seen in section 4.1.1, there was clear evidence of student engagement with the PLAs and subsequent participation in the laboratories. A strong finding was that the PLAs helped the participants feel better prepared for the laboratory and they lead to improved student-teacher interactions within the laboratory environment. As noted by Mshayisa & Basitere (2021), these quality interactions between student-teacher are critical as they have a strong and lasting impact on student retention and performance.

Interaction as a sub-theme was addressed in section 4.1.2. The impact of the PLAs on peer-to-peer interaction was discussed in the Focus Group, and the participants indicated the PLAs improved their confidence, which in-turn led to more collaboration between students as they were more likely to aid students who needed help. This finding aligns with social constructivism which stresses the importance of collaboration among learners, and it echoes Vygotsky's "*zone of proximal development*", where learning happens in collaboration with more capable peers (Matusov & Hayes, 2000). There was a small amount of evidence of poor engagement with the PLAs. As seen in Figure 3, a minority of the participants did not use the PLAs over the four-week research period. In line with previous studies, this indicated that even with the additional resources, some students can still struggle to meet the demands of the challenging laboratory learning environment (Van De Heyde & Siebrits, 2019).

Under the theme of emotional engagement, the sub-themes were '*interest and values*' and '*sense of belonging'*. A primary focus in section 4.2.1 was student feelings around their learning. Statements of feelings from student participants were used to establish their level of interest in learning. Some students made the point that they felt confident and did not feel out of their depth. These were examples of positive emotions aligned with learning. This was consistent with the literature which suggests that positive emotions lead to improved student engagement (Kahu, 2013; Wimpenny & Savin-Baden, 2013). Participants also indicated that the PLAs helped to alleviate negative emotions like stress and worry and prevented them getting bored with the subject. Participants suggested that being well prepared and knowing what we would be doing, helped their sense of belonging in the laboratory, and increased their attendance rate and their ability to see the benefit of attending.

Under the theme of cognitive engagement, the sub-themes were '*motivation and confidence'*, '*persistence*' and '*deep processing of information'*. In section 4.3.1 participants linked preparation to 1) improved confidence in their ability to carry out the laboratory successfully, and 2) their motivation to learn. These findings were consistent with other studies that found that motivation to learn is promoted by feelings of competence (Avtgis, 2001; Cook & Artino, 2016). The findings of this study suggested that the PLAs improved confidence which in turn motivated the students to learn. This study also highlighted that the ability to do the PLAs in their own time, with key content readily available, assisted participants to persist in their learning. It was demonstrated that the PLAs enabled the participants to gain understanding of the material, and that doing the PLAs promoted deep learning as opposed to surface learning. Strong parallels to constructivist theory and CLT - discussed in section 2.0 – were established. The PLAs encouraged active learning, facilitating students to develop understanding by building on existing knowledge and experience. It was shown that well designed PLAs that encourage students to spend time mastering key concepts, enabled them to develop deeper understanding. An important element of CLT, is that these PLAs have the potential to reduce the demand on student short-term memories - since they have mastered the key concepts - and, hence, students' long-term memory can be improved (Van De Heyde & Siebrits, 2019).

5.2 Significance of the study.

This study makes a valuable contribution to the understanding of how PLAs impact on student engagement in the field of computer engineering. The originality of this study relates to the fact that most of the studies pertain to other disciplines. It offers recommendations for the design of the PLAs, and how to use the PLAs to improve teaching and learning in computer engineering. It builds on the existing body of research in the area of resources for laboratory learning, while also evaluating Tinkercad as a support tool. While Tinkercad has been available since 2011, literature studies on its use as a pre-laboratory support tool are few.

5.3 Limitation of the study.

A limitation of the study was the number of students who engaged overall, which was based on the number of student participants within one selected higher education module. This was determined by factors including: the number of students registered on the introductory electronics module, the number of eligible students on that module who volunteered to participate in the study, the number of research participants who attended the weekly laboratories, and the number of focus group volunteers who presented at the focus group. The number of participants in the focus group was 5: the target of 6 to 8, as is best practice, was not achieved as outlined in section 3.2. Furthermore, the focus group participation was based on volunteerism, and not on a random selection of the students, which would have been preferrable. A further limitation of this study was that attendances at the weekly laboratories varied, which meant the number of respondents varied weekly. Therefore, weekly comparisons could not be made, nor a developmental approach included in the analysis. Furthermore, the PLAs were introduced for a four-week period only, in the middle of the semester rather than as a routine part of module delivery, which is not consistent with the literature. Bree (2017, p.15) states that PLAs should be a "*mainstream component of the overall practical experience*". In retrospect, had the PLA being embedded from the start of the module, they might have been regarded with a higher status by the students.

6. Conclusions & Recommendations.

This study set out to evaluate the effects that PLAs have on students' engagement with laboratory learning in HE in the field of Computer Engineering. Objective 1 sought to conduct a literature analysis on pre-practical and pre-laboratory preparation - as a means to enhance student engagement. This literature supported the premise that PLAs are an effective teaching strategy and promote engagement. Increased engagement correlates with better academic performance and increased student retention rates. Objective 2 sought to conduct a mixed methods AR study to determine the effect the PLAs on engagement levels. The findings strongly indicated that the PLAs had a positive impact on students' engagement across the three main themes of behavioural, emotional and cognitive engagement. This study concluded that the PLAs positively influenced attendance, promoted a sense of belonging, supported diverse student learning styles, improved students' confidence and motivation, and encouraged self-directed, deep learning. A key recommendation from this study was to embed the PLAs in the laboratory process from the start, so that students view it as an integral part of their practical work.

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Appendix 1: Questionnaire

Interface Electronics
Laboratory 4: Resistors in Series and Parallel
Group/Date A (15/10/19) B (16/10/19)

PRE-LABORATORY STUDENT FEEDBACK

Please answer these questions as fully as you can **BEFORE** you complete the laboratory.

1. How did you prepare for this laboratory? Tick as appropriate.

☐ I watched the pre-laboratory video.
☐ I used Tinkercad to simulate the circuit.
☐ Other. Please specify:____
☐ I did none of the PLAs (video/simulation). Was there a reason for this? ________
____

- Read the statements below and **circle** the choice that most applies to you.
- If you **did not** use the pre-laboratory resources resume this survey at Q. 8 **after** you complete the laboratory.

2. I enjoyed doing the PLAs.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

3. I can see the value in doing the PLAs to improve my learning.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

4. The PLAs helped me to understand the theory for this laboratory.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

5. The PLAs helped me understand how to build the circuit and take measurements.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

6. I feel well prepared for this laboratory because I did the PLAs.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

Interface Electronics	POST-LABORATORY
Laboratory 4: Resistors in Series and Parallel	STUDENT
Group/Date A (15/10/19) B (16/10/19)	FEEDBACK
Please answer these questions as fully as you can **AFTER** you complete the laboratory.	

7. I feel the PLAs prepared me to complete the tasks independently or with minimal help.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

8. I was fully engaged (paying attention, actively involved etc) during this laboratory.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

9. I understand the theory and I can explain how this circuit works.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

10. I can build this circuit and take the required measurements.

Strongly Agree Agree Neither Or N/A Disagree Strongly Disagree

Explain your choice:

11. Have you any suggestions to improve the PLAs for this laboratory?

12. Have you any suggestions to improve the overall laboratory learning experience for this laboratory?

Thanks very much for your time and valuable contributions.

Appendix 2: Focus Group

Interface Electronics: PLAs

Focus Group Questions

Date 21/11/19

Time 11am – 12pm

(Note-taking and audio recording begins)

Background of and general information about participants

1. Introduce yourself (participants. A, B etc. No names)

State what course are you enrolled in and what group you are in?

Theme 1: Behavioural Engagement with PLAs

2. How did you use the PLAs?
3. How do you feel the PLAs impacted the time and effort you spent learning?
4. What would encourage you to use the PLAs more/better?
5. How did the PLAs impact your interactivity with others?

Theme 2: Emotional Engagement with PLAs

6. What did you enjoy most about using the PLAs?
7. How important/valuable did you feel the PLAs were for your learning?
8. Explain how the PLAs impacted on your feelings of preparation in advance of doing the laboratory?
9. Explain how the PLAs impacted your sense of control over your learning?

10. How do you feel the PLAs impacted your engagement levels in the laboratory?

Theme 3: Cognitive Engagement with PLAs

11. In what way did the PLAs help you understand the theory?

12. In what way did the PLAs help you understand how to build a circuit?

13. How do you feel the PLAs enabled you to gain a deeper understanding of electronics material?

14. How do you feel the PLAs impacted your feelings of confidence in the laboratory?

15. How do you feel the PLAs impacted your motivation to learn?

16. What were the benefits of using the PLAs for your learning?

17. What were the challenges of using the PLAs for your learning?

18. What suggestions do you have to improve the PLAs?

19. Have you any other suggestions to improve student engagement?

20. Have you any suggestions to improve the overall laboratory learning experience?

21. Have you any additional comments/points you would like to make that have not already being discussed?
    Wrap-up and Thanks.
22. Have you any questions in relation to your contributions? Audio recording, data storage etc.
    Session concluded. Audio recording stopped.

Appendix 3: Reflective Journal Template

Interface Electronics

Laboratory 7: KVL

Group/Date A (12/11/19) B (13/11/19)

Date of Reflection

REFLECTIVE JOURNAL

Practitioner Reflection

The purpose of this reflection is to answer the questions:

- How did the introduction of PLAs impact on teaching?
- What were the observed levels of student engagement?
- What was learned about how the introduction of a flipped classroom strategy, in the form of PLAs, impact student engagement?

Description of laboratory environment	Critique your performance. How did you prepare the students for the laboratory practical? What activities did you do, and the students do? Did this change since you introduced the PLAs?

Feelings and/or Reactions	How did you feel the teaching went? How do you think students felt it went? What assumptions did you bring to the laboratory? How did these affect your teaching? What was your reaction to student engagement levels?

Evaluation of Student Engagement	Comment on your personal observations of engagement levels: What was good/poor and why? • Behavioural engagement.

-
  - Participation
  - Interaction levels.
    - Peer-peer collaboration.
    - Asking questions.
- Cognitive Engagement
  - Motivation/Persistence
    - Ability to debug.
    - Work independently.
  - Deep Learning.
    - Quality of worksheets.
    - Asking deep questions

Critical Reflection	What have you learned? Will you manage the next laboratory session the same way? What would you change in the laboratory or PLAs? What have learned about your assumptions and feelings and how this impact on student engagement?

Action plan	What next? Any adjustments you can make before next session? Any changes to feed forward to next cycle of AR?

Questions adapted from Gibbs's Reflective Cycle (1988), G. Costello et al (2015) work on reflection in action research and from Schindler et al.'s (2017, p. 5) conceptual framework of types and sub-themes of student engagement.