# Development of some graduate attributes through constructive alignment for formative assessments of practicals: A case of chemistry students

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**Abstract.** Whether laboratory practicals (LPs) enhance theory learning and live up to expectations in science education or not is an ongoing discussion among researchers. LPs are expected to enhance students' understanding of the theory learned in class and create an opportunity to develop employability skills. However, when LPs become routine and unstimulating, students focus on finishing the practical within the allocated time and acquiring data for post-laboratory assessment, rather than learning. Furthermore, when practical reports are assessed for grading not for developmental purposes, this compromises quality teaching. This is a missed opportunity to develop essential graduate attributes (GAs) like timekeeping, handling skills, safety management, and independent/critical thinking. This research aims to align LPs as continuous assessments to develop some GAs constructively; focusing on laboratory practice, safety, conduct, timekeeping, and housekeeping. This research was conducted in laboratories of the Department of Chemistry at MUT during the first semester of the 2023 academic year. Assessment 'as' learning and 'for' learning was implemented to promote student self-learning and for diagnostic purposes, respectively. A sample of 21 Inorganic Chemistry II students was used. Data was collected using the 3-Likert scale criteria, then analyzed qualitatively and quantitatively. Results indicate that ~50% of students must read the practical manual before laboratory sessions. Moreover, ~20% of the students indicated they need help communicating the practical results; and for ~18%, the LPs are not interesting, revealing that more intervention is needed. The study identified the student GAs that need to be developed to enhance learning and increase employability skills.

**Keywords:** Graduate Attributes, Laboratory Practicals, Constructive Alignment, Assessment


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# 1 Introduction

## 1.1 Background

Teaching and learning (T&L) through practice is integral to any undergraduate science course, such as those in Chemistry and Chemical Engineering. In many educational institutions, science students conduct laboratory practicals (LPs) by following set procedures from predetermined experiments [1]. Despite conducting experiments this way, students expect laboratory courses to enhance their understanding of the theory they learn in lectures [2]. However, studies [3], [4], [5] reveal that this is not always the case because the strict following of laboratory manual instructions becomes routine and unstimulating, and students focus on finishing the practical in the allotted time and gaining the necessary data for the post-laboratory assessment, to the detriment of student learning. Moreover, the assessment *of* student learning (summative) would be mainly through the laboratory reports produced after the sessions and without or with limited assessment during the sessions. This indicates a need for more assessment *for* student learning (formative), and according to Torrance [6], providing good quality feedback to students during a course on what they have achieved and how they might improve will facilitate learning and improve outcomes. In cases where practical reports are assessed for both formative (feedback) and summative (grading) purposes, this would still negatively affect the quality of students that the institution graduates concerning the unassessed laboratory handling skills that form part of student graduate attributes. Hence, the assessment of only the laboratory reports after the sessions, without assessing laboratory handling skills during sessions, does not give an accurate picture of what the students can do and their understanding of the LPs during the sessions. For this research, we defined laboratory handling skills to include laboratory practice (as indicated in practical manuals), safety, conduct, timekeeping, and housekeeping, which students engage in during LP sessions. Some graduate attributes within the Mangosuthu University of Technology's Analytical Chemistry diploma program include analytical and critical thinking, problem-solving, collaboration, creativity, innovation, and entrepreneurship. This research aimed to develop and assess the laboratory handling skills during LP sessions and align the skills to the specified graduate attributes to enhance learning so that the students become competitively employable. Our assessment was valid, fair, transparent, and reliable by employing a constructivist approach that included the students in the planning process.

In order to achieve our objectives, the authors developed rubric criteria and grading, and formative assessment documents based on constructive alignment (CA) [7] of the T&L activities during practical sessions, criterion-referenced assessments (CRA) [8] of the activities, and the outcomes for improvement and enhancement of learning during practical sessions [6]. Lastly, we developed a student evaluation form (formative evaluation) that will assist us in examining the accumulated responses from students to develop direction to improve our T&L [9] **(see supplementary material)**. Lastly, as aspiring humanists and social justice constructivists, the development of this research study would not be possible if the authors' overall T&L practices were not supported and grounded on Biggs' student-centered learning [10], Piaget's cognitive constructivism [11], Freire’s critical pedagogy [12], and Fraser’s social justice disposition [13].

## 1.2 Literature Review

### 1.2.1 Constructive Alignment and Assessment

According to Biggs [7], teachers need to be clear about what they want their students to learn so that they can teach and assess learning accordingly in an *aligned* instruction system. Such an alignment of T&L contains objectives that specify what should be taught, how it should be taught through teaching and learning activities (TLAs), and how student learning is realized through assessment and meeting the set outcomes in a criterion-referenced form of system. Biggs [7] referred to this system as *constructive alignment*.

Assessment has many forms, but not limited to assessment *for* learning (formative), assessment *of* learning (summative) [6], and criterion-referenced [8]. Any form of assessment has to result in student learning; as a result, timeous and quality formative feedback is always necessary. Some essential assessment concepts are that it should be valid, fair, transparent, and reliable and respond to critical calls such as decolonization and transformation. Ramsden [14] says assessment "concerns the quality of teaching as well as the quality of learning: it involves us in learning from our students' experiences and is about changing ourselves and our students. It is not only about what a student can do but also about what it means he or she can do." The involvement of students in all T&L processes should be emphasized.

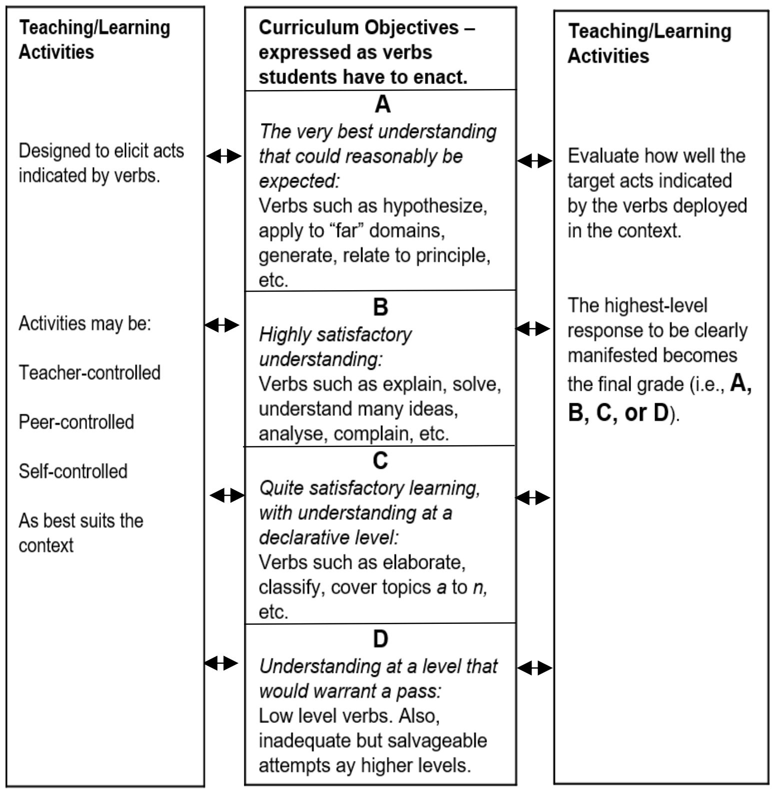


**Fig. 1.** Constructive alignment: Aligning curriculum objectives, TLAs, and assessment tasks [7].

The authors strongly believe that student-student interactions during practical sessions are also essential and are a form of student-centered, deep, and cooperative learning in the sense that students become collaborative rather than competitive [15]. The authors further agree with Boud & Falchikov [16] that grading should be dropped if it inadvertently prompts the students to adopt adverse and unprogressive approaches to learning, which is likely the case with the present assessment of practicals. Benton & Young [9] differentiate between the two forms of evaluation thus: "The process of concluding whether someone is teaching effectively or ineffectively is called summative evaluation. In contrast, when the accumulated evidence is examined to make recommendations on how to improve teaching, educators are engaged in formative evaluation" ([9] pg. 3). Therefore, the formative evaluation that was chosen and conducted by the authors in this research and going forward is likely to lead to improvement and enhancement of student learning of LPs.

## 2 Methodology

The chosen research design is quantitative and causal-comparative in form. The study collected data during five laboratory sessions in semester 1 of 2023. The evaluation sheet focused on the first-year students enrolled for Inorganic Chemistry II for either Diploma in Chemistry or Chemical Engineering. During the practical sessions, the laboratory demonstrators were allocated a group of students to assess using the evaluation sheet, and the researchers played the role of training the laboratory demonstrators before the study commenced and supervised them during the study. After each practical session, students were provided feedback before the following session to consistently improve on the chosen evaluation criteria to enhance their learning [7]. Moreover, students were invited to deeply engage with their practical learning through the open-ended questions at the end of the laboratory session. The qualitative responses sought to assess the logical validity of the competency evaluation sheet, thus making the instrument reliable. The surveys were used face-to-face and cross-sectional for improvement purposes over some time. The experiments in the practical manuals stipulate the requirements and aspects of laboratory practice, safety, conduct, timekeeping, and housekeeping that the students are required to adhere to, although these are not assessed during the sessions, and this formed the basis of our research (refer to rubric criteria and grading document in **supplementary material**). The evaluation criteria included the five laboratory handling skills defined as laboratory practice, safety, conduct, timekeeping, and housekeeping, which are critical competencies for developing the employability skills of science and engineering students. The study uses a criterion-referenced assessment (CRA) ([8] model with levels of achievement that range from 1 (below expectations) to (3) exceed expectations. Guided by the Torrance [6] description of task and quality criteria in relation to outcomes and the importance of being explicit about what is required at different levels of achievement, we have therefore developed a document that describes how the levels of achievement may be reached by the students (refer to rubric criteria and grading document in **supplementary material**). Further, the study solicits the attitude and thinking of students before and during the practical session to achieve the intended learning outcome, which in turn develops employability skills. The questions **in Table 1** are related to employability skills like planning, preparation, generating, and reporting results in a technical context.

The provision of open-ended responses from the students invites a deeper engagement with the statements in the assessment sheet. Moreover, the open-ended questions provides the validity of the responses from the given statements, therefore, taking account of the contestations from previous studies about the validity of the instrument to measure students' performance.

**Table 1.** Assessment of student's competencies before and during the practical session

| **Competency-based questions** |
|---|
| *Attitude:*<br>Are you happy to do the laboratory practical every week? |
| *Ability*:<br>Are you confident in using laboratory instruments? |
| Ability:<br>Can you carry out your laboratory work using standard procedure? |
| *Preparation*:<br>Do you read the practical manual before your laboratory session |
| Planning:<br>Do you plan how you will investigate the practical? |
| Performance:<br>Is it important for you to process the data you found during the practical session? |
| Communication:<br>Do you understand the importance of communicating the results obtained from work? |

The study involved a total of 21 students, comprised of 59% males and 41% females, aged between 18 and 23 years old. Although the study targeted students from both disciplines, Chemistry and Chemical Engineering, it was discovered that only evaluation sheets from Chemistry students were completed correctly. Thus all samples from Chemical

Engineering students were discarded and eliminated from the study. Nevertheless, the study's outcome remained unchanged since the students were in the same class. Moreover, the students in this class were admitted at the same level of performance, as such, there is no difference whether the responses were from mainly Chemistry students. Moreover, this paper presents the preliminary results and Chemical Engineering students will be involved in subsequent research. Although the evaluation sheet did not consider the students' nationality who participated in the study, the study concluded that this factor bears no significance in the study results.

Ethical approval was sourced and granted by the university's ethics committee in compliance with South African National Research Ethics guidelines (2004) and the MUT Research Ethics Policy, Procedures, and Guidelines. The ethical clearance was approved under the project reference number: RD1/02/2023.

## 3 Results and Discussion

### 3.1 Assessment of behavioral skills during laboratory sessions

The practice is that laboratory practicals are done every week, and students submit a final technical report a week later to receive 'formative' feedback. Ironically, lecturers usually pile up these reports until the end of the semester and assess all of them at once for summative purposes. It is shameful to admit that this practice is unjust and denies students an opportunity to improve their writing and presentation skills. It also works against one of our core values as an institution: excellence through consistently delivering high-quality teaching. As such, the assessment rubric used in this study is based on constructive alignment [7] of the teaching and learning activities during practical sessions. The competencies are translated to employability skills like laboratory practice, conduct, time management, housekeeping, and general conduct.

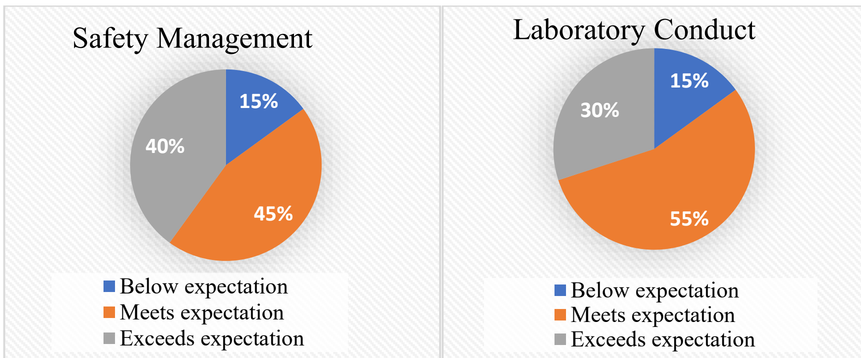


**Fig. 2.** Assessment of (a) safety management and (b) laboratory conduct

Figure 2(a) shows that 45% of the students considered their safety and the safety of those around them during the laboratory session. It is disappointing that 15% of the students were careless and disregarded the safety rules in the laboratory, where there are toxic chemicals that could potentially cause serious bodily harm or even cause a fire. This is a serious concern, considering that these students will be working for heavy chemical industries once they graduate, of which their conduct is hazardous. As expected, figure 2(b) agrees with the 15% of students not conducting themselves well in the laboratory. If a student shows poor conduct in the laboratory, part of that is expected to be attributed to safety management and planning. Even though 55% of students carried themselves well compared to 45% who followed safety rules, the 10% difference could be attributed to other behavioural traits like working neatly in their workstations, cleaning any chemical spillages immediately, and using designated bins to discard chemical waste. Nonetheless, it is a concern to learn that some students still need to work safely in the laboratory even though their enrolled course requires high safety management. This is an area for which academics still need to work on emphasizing the importance of good safety management and the consequences of the lack thereof.

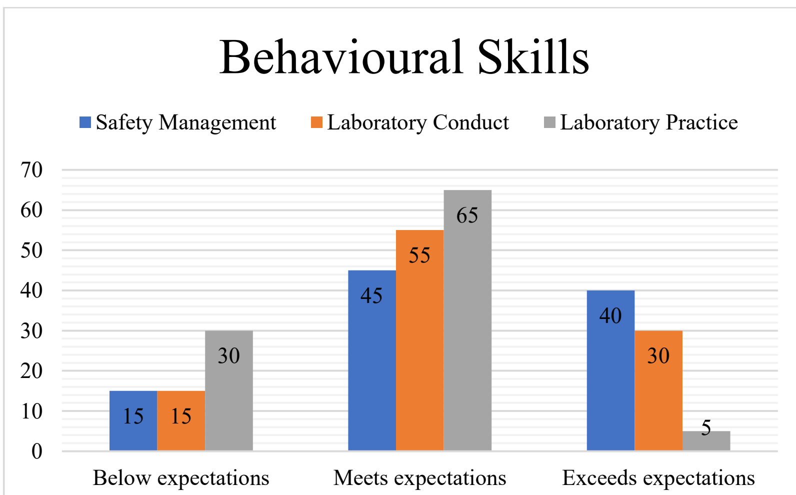


**Fig. 3.** The overall assessment of behavioral trends combined.

An overall view of students' performance was investigated using Friedman's test as a statistical analysis tool. This statistical tool is used for a one-way repeated measure of analysis variance by level [17] where there is categorical and repeatable data. The analysis showed that safety management, laboratory practice, and conduct differed significantly ($p < 0.05$). In Figure 3, there is a clear trend that about 65% of students just met the expectation of the laboratory practice; this result is acceptable but could be better. More efforts should be put towards encouraging students to be interested in their work to exceed expectations. The second most vital skill identified was laboratory conduct; students can follow instructions and perform their work during the practical session. Notably, only 40% of students diligently follow safety management systems in the laboratory. In essence, students need opportunities to develop self-management skills, regulate themselves, and continually remind themselves to do what is right.

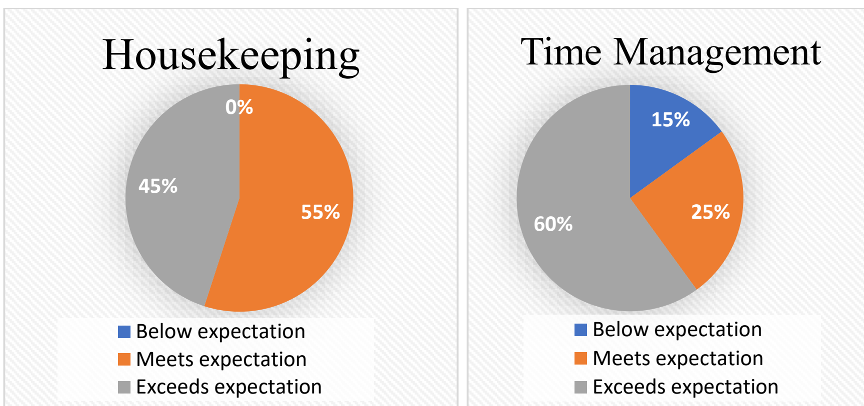


**Fig. 4**. Assessment of (a) housekeeping and (b) time management

Figure 4(a) demonstrates that no students were found to perform below expectations regarding housekeeping. This is a well-acceptable result because this shows that our students are developing a culture of tidying up their workstations, which assists in reducing glassware breakages which may lead to injuries. It is commendable that more than 50% of the students exceed expectations regarding housekeeping in the laboratory. This result was not expected since the overall laboratory practice includes housekeeping, so the assessment outcome was anticipated to be aligned with the behavioral skills trend. In Figure 4(b), there is a worry that 15% of students scored below expectations regarding time management, which is a worry. It is important to note that time management is a skill identified by workplace supervisors, among other skills, as extremely important in the working environment [18]. Even though the time management in this study includes coming to the laboratory in time for the practical session and completing the laboratory activities on time, including doing housekeeping and absenteeism, it would have been better if the assessment was specific to the aspect where poor management was indicated. Nonetheless, these results improved from the study that evaluated the industrial perspectives of chemical engineering students, where 25% of them [students] had poor time management skills [19]. The attribute of time management still needs to be cultivated within our students until we reach a point where all students are assessed as 'exceeding expectation.'

### 3.2 Students' reflection on the laboratory session

About 10% of students said they were not excited to attend the weekly laboratory sessions. This is worrisome because a negative attitude is almost proportional to the performance outcome of any task. This result may be correlated to the 15% of students who demonstrated poor laboratory practice above. However, just above 80% of students demonstrated a positive attitude towards the practical sessions, which is acceptable. On the second reflective question, the same response of, 10% of students said they needed more confidence in using the apparatus/instruments during the sessions, and 80% responded to be quite confident. Another 10% of students were still wondering whether they were excited to do practicals every week or even confident using laboratory apparatus.

Furthermore, students were asked to reflect on safety management in the laboratory, and all responded that they were aware of the safety rules they needed to follow during the session. This is commendable because the laboratory manuals are written for students to understand, and the safety signs are visible and apparent. The safety management question is intertwined with the question of using the standard operating procedures (SOPs) when carrying out practicals, where an almost similar response, where 90% of students are confident with using SOPs. With 10% of the students unsure whether they use SOPs, this result was rather strange because one should know whether they use the standard procedure. A disappointing response was indicated by 45% of students saying they needed to read the practical manual before any laboratory session. This means that the SOPs they confirmed earlier are the safety procedures, not the actual content of Inorganic Chemistry. In addition, about 30% of the students revealed that they needed to plan how to investigate the practical session. These results are consistent with the need for more reading of the practical manual because they can only plan their activity if they have read it.

Lastly, all students indicated they understood the importance of processing the data obtained during the investigation. This is a plausible result because the students in this field need to understand that processing data is their primary function in their nature of work. Also, communication of the results on time is of most importance. About 18% of students responded that they needed clarification on communicating the results and the importance thereof. This is the area where more emphasis is to be placed on academics. Commendably, over 80% of students understand the critical role of efficiently communicating processed data and highlighting concerns.

### 3.3 Qualitative reflective responses on the laboratory practice assessment

As a final instrument to solicit information on the assessment of laboratory practice, students were asked open-ended questions on their view of the importance and assessment of the practical. One student said*, "Yes, it is necessary because it helps us understand what is done in class, and it helps us understand the purpose of doing I"*. Students know that the laboratory practical is there to integrate theory learned in the classroom with practice [20]. This response is positive and affirms that there is a visible alignment of the curriculum regarding theory which is merged with practice. On the other hand, another student responded*, "It is necessary for practicals to be assessed the way they are assessed because they teach me to be more careful how we do the practical and, again, more knowledge when we are in the industry."* Again, students demonstrate an understanding of the expected learning, which prepares them for the world of work.

Another response said, "*Yes, I do think so; I think the [laboratory] demonstrators assisted are very much necessary as they clear any confusion that one might have with the practical procedure, gases, and procedure*." Students recognize the role of laboratory demonstrators, and the value they add to their learning process is pleasing. Also, the response said, "*I think it is necessary; it teaches us how to behave in the laboratory following all the safety procedures accordingly, as laboratories are a hazardous place to be. This is the purpose of Analytical chemistry".* Students reflect on the safety management aspect, which is over-emphasized during the laboratory session. Moreover, they indicate they understand their role in the laboratory, even mentioning this as their job purpose. While another student highlights that "*The laboratory must improve safety goggles; the ones we are using are not comfortable*." This study assisted students in voicing the things they were not happy with, like the uncomfortable goggles. Even though this study was not meant for such reviews but rather a reflection of practical practice assessment, this comment shows that students are usually timid to report their issues, so they used this platform to raise their issues.

Interestingly, one student said*, "It is necessary for practical to be assessed this way because after finishing diploma* [meaning theory part of the diploma]*, we do in-service training whereby we are being assessed. It also helps us to be more active*". Again, students identify the importance of continuously being assessed because they know the end goal.

## 4 Implications and contributions to knowledge

The preliminary results of this study suggest an integrated academic learning with theoretical learning that promotes the development of graduate and employability skills within the curriculum. This should be a detailed and structured approach to an integrated curriculum, which will be assessed and monitored to achieve the intended outcome on the developed skills. Adequate planning of the learning environment is critical towards creating an innovative, flexible, and adaptable opportunities leading to assessment of cognitive skills [21]. Ultimately, this strategy potentially contributes towards the cognitive knowledge, and students' self-actualisation. Students are forced to be responsible for their learning and thus will reflect on their actions throughout the learning activities. Finally, the proposed integrated learning strategy will overall improve the quality graduates with necessary set of skills to enter the world of work.

The future study will extend to students from other departments to ensure a broader representation of students, thus giving a more informed curriculum to other STEM disciplines. A well-rounded approach in assessing for learning gives a pathway to knowledge access and skills for life-ling learning. Such an approach propels students to exercise their agency and be good citizens when they are able to locate themselves in the learning cycle.

## 5 Conclusions

This aim of this research was to develop and assess the laboratory handling skills during LP sessions and align the skills to the specified graduate attributes to enhance learning and improve employability of students. The data collected excludes that from assessed students' practical reports that would have assisted to identify potential improvement of learning. The study found that more than 40% of the students seem unsure about the critical operational procedures during practical sessions, mainly because of poor planning, lack of reading SOPs, attitude, and time management skills. Considering that the chemistry environment is a competitive industry with more laboratories becoming ISO accredited, this calls for highly skilled graduates. The study concludes that the lack of handling skills in the laboratory may be correlated to the students' graduate attributes deficiency in the future if not corrected. As such, it is crucial that academics re-evaluates their teaching and assessment strategies and explore different approaches to developing these skills in the students. These skills' ongoing or continuous assessment is vital to keep students engaged in their learning and development. *The study proposes a genesis* approach, where the skills are a part of the curriculum and are embedded in all subjects for more emphasis and development.

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