Literacy across the Curriculum in the Engineering Sciences: A Case Study of a Course in Concrete Technology

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Abstract

Engagement with engineering professionals on the part of the authors has, at times, yielded dissatisfaction with the quality of engineering graduates, particularly with respect to verbal and written communication abilities. It is thus clear that engineering curricula must do more to develop these abilities more overtly within engineering degree and diploma programmes. To this end, the development of academic literacies (reading, writing, critical thinking and speaking) must be incorporated into engineering content modules. This requires the development of literacy across the curriculum.

This paper analyses the literacies embedded in one particular module offered as part of the degree in Civil Engineering Science at the University of Johannesburg, namely Concrete Technology. The analysis is undertaken using a two-pronged methodology. First, a quantitative analysis of the stated outcomes and assessments given in the course is undertaken in terms of Biggs' SOLO taxonomy. Thereafter, a qualitative description of the module within the framework of nine central literacy practices required of engineering graduates in South Africa is given.

The aim of this analysis is to understand the literacy practices currently embedded within the course so as to identify the areas in which the course can further develop students' academic literacies. Biggs' SOLO taxonomy is used as it provides an easy to use (and understand) means of measuring a) the extent to which higher order cognitive demands are being placed on students and b) the degree of alignment between the modules stated outcomes and the assessments given. This paper works from the assumption that a clear understanding of current practice within individual courses is necessary prior to the implementation of literacy across the curriculum. This is to ensure that individual courses within engineering degree and diploma programmes scaffold students' participation in the literacy practices of the various engineering sub-disciplines.

Introduction

An external examiner of our final year Civil Engineering students' research project reports wrote in her examination report, that certain skills "need to be developed in the students in order to more satisfactorily achieve the ECSA [Engineering Council of South Africa] outcomes". The examiner went on to list and discuss these skills as follows: grammatical, spelling and punctuation errors, appropriate style of writing for the target audience, document layout, logical argument and appropriate use and integration of graphical content. The examiner also wrote of the importance of students being "coached in the concept of a 'golden thread' ... that ties each section in the report to all those that precede or follow it", and elaborated that "each part of the project fits together ... to form a complete picture".

This concern with appropriate written communicative competencies is echoed by many engineering professionals, who argue that while graduates may possess the technical skills and know-how to be competent engineers in practice, they often lack competence in professional written and verbal communication. Such competence offers engineering graduates a competitive edge in the workplace and assists them in attaining leadership positions. It is thus imperative that engineering degree programmes offer students opportunities to master the literacies required of them during study and after graduation.

According to Boughey (2002; 2007), academic development efforts have often adopted a deficit approach and have focused on so-called underprepared or non-traditional students. However, most, if not all, engineering students need practice in the particular literacy practices employed within the Engineering sciences. Previous models of addressing this matter have included the development of stand-alone ‘communication’ or ‘literacy’ courses (Kloot, Case and Marshall, 2008). However, in order to overcome the shortcomings of these courses, the idea of literacy across the curriculum has become popular. This involves embedding the use and development of literacy practices within the context of mainstream or core disciplinary content (Davidowitz, 2004). Within the context of Engineering at the University of Johannesburg, where literacy across the curriculum has not been implemented to any real degree, it has become necessary to first analyse what is ‘going on’ in individual courses, by way of literacy practice, before steps can be taken to enhance the development of student literacies within those courses.

In this paper, we analyse the literacy practices embedded in a particular course offered as part of the degree in Civil Engineering Science at the University of Johannesburg, namely Concrete Technology. Concrete Technology is offered at second year level and is one of the first ‘proper’ engineering courses in the degree (the first two years of the engineering degree programmes largely consist of courses in mathematics and physical science offered by the Faculty of Science). Because of its early appearance in the programme and because students have engaged in little literacy practice prior to entering the course, it is an ideal vehicle for the incorporation of literacy development. To this end, below, we discuss the methodology used to analyse the Concrete Technology course and use this methodology to discuss ways in which the course can be amended to include more in the way of focused literacy development within the course content.

Biggs’ SOLO taxonomy

Because Biggs’ Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs, 2003) is used extensively in the work described in this paper and because it may not be familiar to all readers, it is necessary to provide a brief explanation of this taxonomy. Those readers already familiar with the taxonomy may want to skip this section.

Biggs’ SOLO taxonomy consists of five levels. The first of these is prestructural understanding where students demonstrate little or no understanding. Students at the next level, unistructural understanding, are able to understand terminology and little else. Students at a multistructural level understand concepts but can only knowledge-tell and cannot relate parts to a whole or apply knowledge across contexts. The penultimate level of understanding on the SOLO taxonomy is relational understanding, where students can do more than simply list facts; they can apply and relate knowledge across contexts. Finally, at an extended abstract level of understanding, students are able to engage in high-level conceptualization, abstraction, hypothesis-generation and theorization.

The first three levels of the SOLO taxonomy represent a quantitative phase where students understand more or less. However, the last two levels of the taxonomy represent a qualitative phase where students engage with course content in qualitatively different ways. Thus, as students move across Biggs' SOLO taxonomy, they must first increase their knowledge (quantitatively) and then deepen their understanding (qualitatively) (Biggs, 2003: 41). Essentially, the SOLO taxonomy allows us to understand that the development of students as readers, writers and critical thinkers requires a shift away from outcomes and assessments that represent a low level of understanding towards higher-order cognitive demand.

Analysis: Literacy practices embedded in Concrete Technology

Figure 1 depicts the methodology employed in understanding the literacy practices embedded in the Concrete Technology course. In this section, we present our analysis of the Concrete Technology course in terms of this methodology. We stop short of offering any interpretation or discussion of the findings of the analysis in this section. Instead, such interpretation and discussion is reserved for the section that follows. As is indicated in the figure, the point of departure was to analyse the module outcomes in terms of the level of cognitive demand they require from students. In total, eight outcomes are listed for the Concrete Technology course. These are depicted in Table 1.

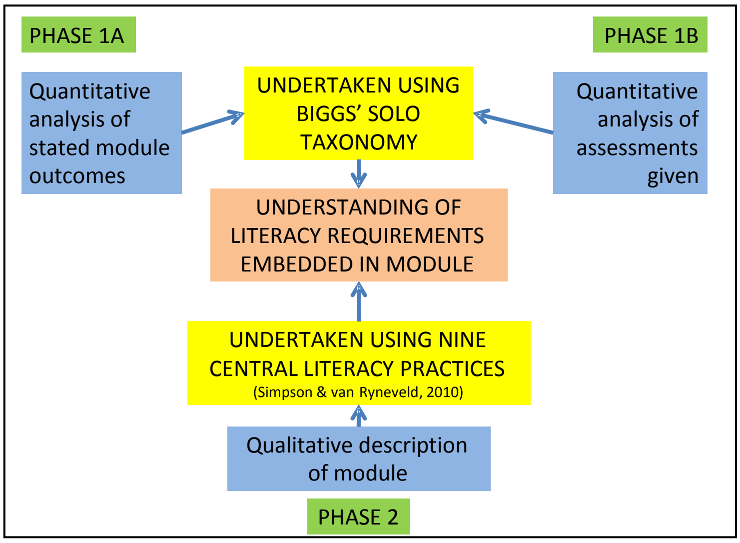

Figure 1. Diagrammatic depiction of methodology

From Table 1, it is evident that the outcomes listed for the Concrete Technology course are pitched at an advanced level of cognitive demand. That is to say, each one of them requires students to demonstrate an ability to *do* something with the knowledge they have gained in the course, rather than simply reproduce that content. The outcomes therefore suggest a qualitatively deeper understanding of the module content.

The next step in the analysis required an investigation into the assessment opportunities provided for in the course. To allow for comparison, Biggs' SOLO taxonomy was used again. Assessment in the Concrete Technology course consists of one practical (lab) report and three semester tests (as well as a further sick test), as well as a final, summative examination. Table 2 indicates the relative weighting of these respective assessments.

Table 1. Outcomes of Concrete Technology classified according to SOLO taxonomy

#	Outcome	SOLO Classification
1	Apply basic scientific fundamental knowledge to properties of concrete in fresh and hardened state	Relational
2	Apply scientific fundamental and specialist knowledge to concrete constituents: cement aggregates, admixtures and additives	Relational
3	Design a proper concrete mix for durable concrete	Extended abstract
4	Apply basic scientific fundamental knowledge as well as specialised knowledge of properties of fresh concrete, to formwork for concreting and various architectural finishes	Relational
5	Plan and conduct investigations and experiments, using diagnostic procedures and appropriate equipment, to analyse concrete degradation and propose a repair or rehabilitation plan for these concrete structures	Extended abstract
6	Apply knowledge of physical laws to the methods of transporting and placing concrete	Relational
7	Apply scientific fundamental and specialist knowledge to production processes	Relational
8	Apply knowledge of basic sciences and specialised knowledge to concreting under hot and cold weather conditions	Relational

Table 2. Assessments in Concrete Technology

Assessment Methodology	Weighting
Semester tests (x 4)	30%
Practical (lab) report	20%
Examination	50%

Table 3 summarizes the level of cognitive demand (according to the SOLO taxonomy) in the Concrete Technology course. As can be seen in Table 3, some questions in the tests and exam required the performance of calculations or sketching of illustrations. Because the focus of the analysis was on reading, writing and critical thinking, it was decided to separate these questions out from the main analysis. However, it should be noted that these questions generally require the application of content knowledge and are therefore likely to require relational understanding. Furthermore, it is important to note that quantitative literacy and multimodal literacy are both, of course, extremely important literacies within engineering.

As can also be seen in Table 3, each of the four tests is weighted at 7.5% of the overall mark for the course. Each test is actually weighted at 10% and students would in fact only write three of the four tests. However, in order to maintain proportion in the analysis, it was decided to scale down the weighting for the tests. Furthermore, for the purpose of the analysis, the practical (lab) report was classified as requiring relational understanding as it demanded of students to understand the effects of certain variables on the properties of fresh and hardened concrete. It was decided not to classify it as extended abstract because it stopped short of requiring students to generate arguments or propose recommendations based on the lab test results. As a final note, the last column in the table represents the total proportion of the course assessment which requires each type of assessment as classified according to the SOLO taxonomy. This proportion takes into account the relative weighting of each assessment opportunity.

Table 3. Classification of Concrete Technology assessments according to SOLO taxonomy

SOLO Classification	Test 1	Test 2	Test 3	Sick test	Practical (lab) report	Exam	Total
Total Marks	50	50	40	60	100	100	400
Weighting	7.5%	7.5%	7.5%	7.5%	20	50	100
Prestructural	0%	0%	0%	0%	0%	0%	0%
Unistructural	6%	14%	0%	0%	0%	4%	3.5%
Multistructural	18%	50%	57.5%	40%	0%	21%	22.9%
Relational	48%	26%	25%	20%	100%	8%	32.9%
Extended abstract	0%	10%	0%	6.7%	0%	6%	4.3%
Calculations / Illustrations	28%	0%	17.5%	33.3%	0%	61%	36.4%

As can be seen, approximately 37% of the course assessment requires relational or extended abstract understanding of the course material, while another 36% requires students to perform calculations or sketch illustrations. The remainder of the course assessment requires reproduction of information given in lectures or in the textbook. That is, about 26% of the course assessment requires unistructural or multistructural understanding of course content.

The second, and final, aspect of our analysis involved a qualitative description of the module in terms of nine central literacy practices required of engineering students upon graduation. These literacy practices are discussed in detail in a previous paper (Simpson and van Ryneveld, 2010). Table 4 summarizes these central literacy practices and indicates which ones are practised in Concrete Technology.

Table 4. Assessment of Concrete Technology according to central literacy practices identified in Simpson and van Ryneveld (2010)

Category	Literacy Practice	Practiced in Concrete Technology?
Reading	reading across multiple text types and disciplines	N
	discerning essential (or relevant) from non-essential (or irrelevant) information	N
	comprehending, summarising, paraphrasing, synthesising and referencing information from other sources	N
Writing	language competence	Y
	audience-awareness	N
	purpose-awareness (or text-type awareness)	N
Critical Thinking	argument, evaluation and reasoning	N
	reflection and independent learning	N
	relational and analytical thinking (or the ability to apply knowledge)	To Some Extent

In terms of our analysis, it can be seen that the Concrete Technology course, as it stands, does not offer students opportunities to practice many of the key literacy practices needed at graduation. One practice that is incorporated into the course is language competence. Because it is built into the assessment rubric for the lab reports, students are made aware of the need for linguistic accuracy in their technical report writing. In addition, as indicated in the quantitative analysis, the outcomes and assessments in the course place emphasis on relational and analytical thinking. However, whereas the outcomes suggest that such relational thinking constitutes the bulk of the course, the assessments place relatively less importance on this. It is for this reason that our finding is that relational thinking is practiced *to some extent* in the Concrete Technology course.

Discussion: Implementing Literacy Development within Concrete Technology

The goal of the above analysis of the Concrete Technology course is to provide a clear understanding of current practice within this course. Such an understanding of individual courses is necessary prior to the implementation of literacy across the curriculum. This is to ensure, in line with social constructivist principles, that individual courses within engineering degree and diploma programmes scaffold students' participation in the literacy practices of the various engineering sub-disciplines. To this end, three factors bear consideration with regard to developing the Concrete Technology course so that it better contributes to the development of student academic literacies.

First, attention needs to be paid to how the Concrete Technology course interacts with parallel, preceding and succeeding modules in the curriculum so that students' mastery of academic literacy practices is adequately scaffolded. Second, given its location within the overall programme, decisions must be made about which literacy practices should be focused upon within the Concrete Technology module as well as what degree of cognitive demand is appropriate for this module. Finally, investigation should be undertaken into aspects of writing intensive teaching that may be implemented within the context of the Concrete Technology module.

Each of these three points is discussed below.

Concrete Technology and the Civil Engineering Science degree programme

Attempts at reforming engineering education can occur at a number of levels; these include the level of the individual course and whole programme level (Crawley, Malmqvist, Ostlund and Brodeur, 2007). In this paper, we focus our discussion at the level of the individual course. However, we further argue that the development of student literacies must occur throughout our engineering degree programmes. As such, the development of a course such as Concrete Technology must be seen as just a beginning of a much larger initiative aimed at programme reform. Concrete Technology is a useful point of departure for our purposes as the structure of the Civil Engineering Science degree is such that the first year and a half is dominated by Mathematics and Physics courses. Concrete Technology is among the first 'engineering' courses that students encounter in their degree studies. Because of its relatively early placement in the curriculum, Concrete Technology must act as a springboard from which students' literacy development can be enhanced in the courses or modules that follow it in the curriculum.

Such scaffolding of student academic literacy development is in line with much of the recent literature on the subject. For example, Paxton (2007) argues that students are in a process of 'interim literacy' as they master the literacy practices of their chosen discipline. The notion of interim literacies forces universities to acknowledge that these practices need to be mediated through degree programmes. Paxton's argument is similar to that of Jacobs (2007) who argues that the development of academic literacy is not something that can be undertaken at first year level only; instead, it occurs over the course of the entire undergraduate degree and should in fact be seen as one of the goals of a degree programme. Furthermore, Kloot, Case and Marshall (2008) argue that development of mainstream university curricula should not be limited to first year but should be infused into all years of study. It is clear then that scaffolding of student literacy development should take place such that it achieves the aim of creating a "coherent curriculum in which all courses have well-defined and interconnected roles in achieving the programme mission" (Felder and Brent, 2002).

An example of the integration of student academic literacy development within and across university modules has been offered by Crawley et al (2007) at Chalmers University of Technology in Sweden. In this example, the authors illustrate how a number of courses within a Mechanical Engineering degree programme work in tandem to develop students' written and oral communicative competence. For example, a course at first year requires students to write a technical report and deliver an oral presentation. The course provides students with input into how to write technical reports, how to deliver effective oral presentations and how to incorporate multimedia, amongst other topics. In addition, discussion around these issues is promoted in class. These abilities are then practiced in later courses where further aspects such as critical thinking and poster production are introduced. The courses thus build up in complexity until the final year thesis requires students to put into practice all of the abilities developed during the course of the programme.

While the example given here may resemble what happens in countless other programmes, the fact that it is undertaken systematically and explicitly is important. The value of the Concrete Technology course within the larger Civil Engineering Science programme must be similarly systematically and explicitly described in terms of its contribution to the development of student academic literacies. It is to this point that the following subsection turns.

Which literacy practices and what level of demand?

According to Evers, Rush and Berdrow (1998), the development of student competence requires curricular reform such that each course makes a contribution to the goals of the program. They further argue that this can be undertaken through the analysis of specific courses according to a matrix of competencies. To return to the list of literacy practices discussed above that were posited by Simpson and van Ryneveld (2010), this would require decisions to be made around which of the nine literacy practices ought to be focused upon within Concrete Technology. Because of its relatively early placement in the curriculum, it may be prudent to focus on the reading and writing practices in this course and leave the critical thinking practices to courses later in the programme. It is important to note that no one course need cover all the literacy practices; instead, they should be covered across the sum of the courses (Evers et al, 1998).

In addition to decisions around which literacy practices should be incorporated into the Concrete Technology course, decisions must also be made with regard to the level of cognitive demand placed on students within the course. This is important as, in order to benchmark program effectiveness, objectives should be explicit about how students should perform at key milestones and at graduation (Mentkowski and Associates, 2000). To this end, Biggs' (2003) levels of student engagement with course content are helpful. Biggs' levels are depicted in Figure 2 and range from low-level to high-level engagement.

High-level engagement	Theorizing
	Applying
	Relating
	Explaining
	Describing
	Note-taking
Low-level engagement	Memorizing

Figure 2. Biggs' Levels of Engagement with Course Content (Biggs, 2003)

According to Biggs (2003), good teaching involves getting students to use the higher level processes (such as theorizing and applying). However, as with the question of which literacy practices ought to be covered, not every course need require such high-level engagement. For example, it may be sufficient for a course at second year level, such as Concrete Technology, to move as far up the ladder of engagement as 'relating' without going any further. This is because students need to be given the opportunity to master simpler tasks before moving on to more complex ones. The importance of this is well-illustrated in James Gee's 2003 study of children's learning of video games. In this study, Gee argues that people need to be introduced to problems in carefully selected orders: problems that are too complex and presented too early do not promote effective learning. In addition, as Gee argues, good games create expertise by giving players multiple opportunities to practice skills until they are mastered before new skills are required; these new skills are then integrated with and developed from the old, mastered skills.

Writing intensive teaching

The following quotation is taken from the minutes of a meeting of the American Society of Engineering Education held in 1897, more than a century ago:

> My practice … was to take as a reading book for the class in chemistry in the Junior year a well-known German periodical of analytical chemistry after the class had had one year of preparation in German grammar and in simple reading exercises. The students were generally appalled at the idea that they were expected to read a work of this character after (as they thought) so slight a preparation, and they were astonished to find in the course of a few weeks that the exercise had lost all terror for them. After a few hours in the class room, in which I found out how much they knew about the construction of German sentences, I began to discuss with them the subject-matter of the articles we were reading. By selecting subjects with which they were more or less familiar, and operations which some of the members of the class were, perhaps, working on in the laboratory, the exercise became a chemical conference on recent German literature. By holding to this idea throughout the remainder of the year the students lost sight of the language in the matter, and during the Senior year there were very few students of chemistry who did not consult German books in the library with ease and confidence.
>
> (American Society for Engineering Education, 1897: 252 – 253)

This testimony illustrates the importance of the development of student literacy (in this case literacy in German) within the context of course content. Like the engineers-in-training in 1897 who needed fluency in a foreign language, many of our students today are studying engineering in a language with which they do not necessarily have full familiarity. Even those students who are fully conversant in English may well struggle due to the highly technical and specialized language of engineering. As such the development of written communicative competence must be developed within engineering courses. This requires the implementation of writing-intensive teaching.

As Evers et al (1998) argue, lecturers must grade not only content but also oral or written presentation of that content as there is little point in focusing on content if the communication of that content prevents its comprehension and communication. This argument is supported by Sulcas and English (2010) who argue that the work of the engineer requires advanced communication skills and it is therefore important for universities to equip students with the ability to communicate effectively across professions. As mentioned above, this relies on scaffolding students' participation in the literacy practices of the engineering profession.

According to Kalman (2008), scaffolding implies that activities need to be designed in order to nurture the growth of students' intellectual development. Kalman (2008) continues that a number of factors hinder student learning in science and engineering which can be overcome through an approach to scaffolding that includes a variety of interventions in the classroom. This is in accordance with Biggs' (2003) argument that successful teaching for learning ought to be concerned with what students do during learning rather than with what teachers do. One of the ways of scaffolding student learning is to encourage students to engage in reflective writing (Kalman, 2008).

Writing is not only a valuable tool for communication, but it can also be used to assist student learning (Young, 1999). Writing to learn is a technique that assists students in meeting expectations with regard to higher-order thinking as it helps them to apply and internalize the importance of what they have learnt rather than simply memorize information (Kalman, 2008). Such reflective writing tasks, however, should not require students to merely summarize what has been covered in the textbooks or lectures; instead, it should require them to establish connections and build their knowledge (Kalman, 2008).

A Practical Example

The above discussion has demonstrated, rather theoretically, the need for reform within the Concrete Technology course, not because the course is problematic, weak, poor or wrong, but because there is a need for more focused, explicit and systematic development of student academic literacies within the curriculum and Concrete Technology was identified as one of the courses which lend themselves to such development. In the paragraphs that follow, we now describe, in more practical terms, some of the changes that are being introduced to the Concrete Technology course.

The first significant change to the course is the incorporation of a literature review report on a topic of the students' choosing. Such a project will provide students with the opportunity to practice the key reading practices of discerning essential from non-essential information and the ability to read, paraphrase, integrate and synthesise information from other sources. However, because this, in most instances, will be the first time students are expected to engage in these kinds of activities, the decision was also made to incorporate the development of these abilities into the course content. To this end, the decision was made to include a class that provides focused input on synthesis and integration of sources as well as on avoiding plagiarism. Such a class would aim to prepare students for the submission of the literature review reports.

A second change made to the course pertains to the lab report. Prior to this project, Concrete Technology students were required to produce one fairly large lab report at the end of the semester. However, the decision was taken to now include three shorter lab reports spaced throughout the semester so that students are able to receive feedback on and in turn improve their lab report writing during the semester. In addition, it was also decided to assess these lab reports, in part, against an assessment checklist that clearly details the expectations of a successful scientific lab report. In this way, students would be able to rather clearly identify the ways in which their future lab reports need improvement.

Thirdly, the tests in the Concrete Technology course were revised such that the first test focuses on rather lower-order concerns of understanding course content whereas the second test then requires of students to engage in the higher-order engagement activities of analysis, evaluation and application.

Finally, it was also seen as important to look at classroom practice within the course. To this end, it was decided to re-structure lectures to include more demonstration and discussion of the application of the theory of Concrete Technology.

The changes described in this section, we would argue, have the potential to dramatically improve student learning within the course and will go some way towards giving students the required practice with the reading, writing and critical thinking practices they need to master for the rest of their studies and for their working life. However, attention needs also to be given to how other courses within the programme also contribute to students' academic literacy development. Furthermore, the implementation of these changes needs to be tracked so that the impact thereof can be clearly studied to ensure that they achieve their intended goals.

Conclusion

It is important to note that the Concrete Technology course, as it stands, is not dissimilar from any number of other university courses in South Africa and abroad. As such, the point of this paper is not to argue that there is anything 'wrong' with the course or that it is 'weak', 'inappropriate' or 'bad'. However, if our students lack the communicative competence they need upon graduation, as engineering educators, we need to revise our approach and 'do things differently'. To this end, the argument present in this paper is best summarised as follows:

1) Engineering students often struggle with the literacy challenges they are faced with during the course of their study.
2) The development of student literacies not only better prepares students for the world of work; it also assists them in learning the content of their various engineering courses.
3) Therefore, an analysis was undertaken of the literacy practices currently embedded within a course on Concrete Technology so as to identify the areas in which the course can further develop students' academic literacies.
4) This analysis was two-pronged. First, Biggs' SOLO taxonomy was used to examine the extent to which higher order cognitive demands are being placed on students and the degree of alignment between the modules stated outcomes and the assessments given. Second, a qualitative analysis of the course in the context of key literacy practices evident in documentation from the Engineering Council of South Africa was undertaken.
5) The results of the analysis reveal that the *outcomes* suggest that a qualitatively 'deep' understanding of the module content is required while a sizeable portion of the course *assessments* require relational or extended abstract understanding of the course material; in addition, within the context of key literacy practices evident in documentation from the Engineering Council of South Africa, it can be seen that the Concrete Technology course offers students opportunities to practice some of the literacy practices required at graduation and beyond.
6) The paper concludes that a clear understanding of current practice within individual courses is necessary. This is to ensure, in line with social constructivist principles, that individual courses within engineering degree and diploma programmes scaffold students' participation in the literacy practices of the various engineering sub-disciplines.
7) Three recommendations are made with regard to developing the Concrete Technology course so that it better contributes to the development of student academic literacies.
   a. First, decisions must be made about which literacy practices should be focused upon within the Concrete Technology module as well as what degree of cognitive demand is appropriate for this module given its location within the overall programme.
   b. Second, attention needs to be paid to how the Concrete Technology interacts with parallel, preceding and succeeding modules in the curriculum so that students' mastery of academic literacy practices is adequately scaffolded.
   c. Finally, the paper discusses aspects of writing intensive teaching that may be implemented within the context of the Concrete Technology module.

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