The CCAILM learning model: an instructional model for teaching and learning of engineering modules

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Abstract

This research report presents a new teaching and learning model in engineering classes. The proposed learning module is called the "Constructionist Computer Aided Instructional Learning Model" (CCAILM). This new model was derived from constructionist learning theory, the media-affects-learning hypothesis and the multiple representation principle. The process of knowledge construction, when an engineering lecture is delivered and learnt using a CCAILM approach, as well as the instructional strategies and steps prescribed in the CCAILM teaching and learning environment, are also discussed in this report.

Key words engineering education, undergraduate, engineering modules, learning and teaching models

Introduction

The development of the Constructionist Computer Aided Instructional Learning Model (CCAILM) is informed by the need to improve both the quality and quantity of engineering students graduating from South African universities. Indeed, this has now become imperative, given that engineering practices have direct economic consequences on the general wellbeing of both nation-building and the people of South Africa.

It is generally known that a sound knowledge of science and mathematics is a prerequisite for studying engineering at higher institutions of learning. However, despite the importance of science and mathematics, the majority of high school students have developed a fear and dislike of these fields of study, simply because of the uninspiring ways these subjects are taught in both high schools and universities (Gallagher, 2000). Note that Gallagher observed the teaching and learning approaches to science and mathematics (at both high school and university) in six countries throughout the world for a period of 15 years. These countries included South Africa, the United States of America, Australia, Brazil, Thailand, and Taiwan. He discovered that, for the period of the study, the teaching approaches of sciences and mathematics at both high schools and university conform to traditional teaching and learning approaches: the teacher or lecturer comes to the classroom prepared, presents the prepared notes and then the students are expected to copy these notes (Gallagher, 2000).

Furthermore, the baseline study (Faleye & Mogari, 2010) carried out as a forerunner to this research report revealed that, even after almost a decade Gallagher reported his findings, the teaching and learning of fluid mechanics (a branch of mathematics) in mechanical engineering classes in South Africa continued to follow a traditional

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approach. According to Faleye and Mogari (2010), this teaching and learning approach presents students with learning difficulties in at least some aspects of the fluid mechanics module reviewed.

However, studies (Dijk & Jochems, 2002; Gallagher, 2000) have shown that traditional teaching approaches lead to a superficial conceptual understanding or misconceptions on the part of students. Examinations and tests are regarded, by students, as only requiring a recall of facts based on the teacher's or lecturer's notes. This implies that students memorise purely to pass examinations and tests, and do not bother to understand the concepts they have learnt.

Like in other science-oriented courses, engineering students (which are the focus of this report) need to gain a deep understanding of the theoretical information learnt in the classroom, so that they can connect this information to engineering practice. Failure to achieve this may well lead to universities and colleges turning out engineering graduates who may not meet the industrial skill demand. Perhaps engineering educators who belong to the "church" of traditional teaching approaches believe that, by transmitting their knowledge to their students through lecture notes, their students somehow naturally come to understand what it is they are being taught. However, as Vygotsky (1978) noted, knowledge is socially and cultural constructed and not transmitted. There is therefore a need to enhance the teaching processes in engineering classes to accelerate learning, and to facilitate an in-depth understanding of engineering concepts (Marek & Aleksander, 2005).

Besides the inappropriate learning challenges that form part of most engineering modules, as discovered by Gallagher, (2000) and Faleye & Mogari, (2010), other challenges in the contemporary engineering classroom include the following: an ever-growing number of students in a given classroom and the need for multi-disciplinary teaching in order to minimise teaching duplication and cost (Dearn, Tsolakis, Magaritis & Walton, 2010). In this regard, many studies (Ngo & Lai, 2001; Steif & Naples, 2003; Hall, Philpot & Hubing, 2006; Cleghorn & Dhariwal, 2010) have been undertaken in order to address these challenges. Nevertheless, a comprehensive teaching and learning strategy, which in itself would solve many of the problems confronting the teaching and learning of engineering modules, remains elusive. It is against this background that the author of this report developed the CCAILM learning model, with a view to addressing the teaching and learning challenges encountered in engineering classes.

Review of recent studies

In recent years, many studies have reported on how engineering instructors have attempted to improve students' learning by incorporating computer-based instructional aid in their classroom teaching (e.g. Bowe, Jensen, Feland & Self, 2001; Reamon & Sheppard, 1999; Rhymer, Jensen & Bowe 2001; Ngo & Lai, 2001). There is now clear evidence (Akst, 1996; Kadiyala & Crynes 2000) that computer-based instructional approaches are both more effective and more efficient than conventional teaching.

Steif and Naples (2003) used computer courseware to address the problem of students' problem-solving skills in traditional teaching settings. The authors noted that, in mechanics courses, students need to learn to apply fundamental principles to facilitate understanding, problem-solving and design. Problem-solving courseware modules were therefore developed to facilitate this process. In the courseware, a number of problems were solved (as examples) and the students were given many other exercises to work through. This approach was based on the belief that, by solving a number of similar, but non-identical problems, students would be able to elucidate the underlying fundamentals more readily than by memorising an independent method for solving each type of problem (Chi, Feltovich & Glaser, 1981). The developed courseware CDs were handed to students, who were expected to practise problem-solving on their own. The courseware was also made available to students online. According to Steif and Naples (op. cit), students found the courseware beneficial. Nonetheless, the authors warned that the courseware alone could not meet the learning needs of all students.

In fact, I regard Stief and Naples' work as a traditional "practice and drill" learning approach, an approach that encourages a superficial understanding of the knowledge that engineering students are required to master. I feel that students should not be restricted to memorising the problem-solving procedures alone, but need to be taken through a learning approach that will enable them to gain a much deeper understanding of the various engineering modules presented in universities and colleges. Perhaps a better result would have been obtained if the problem-solving skill concepts in the courseware were animated (as in ACIA) and the instructional strategy as in CCAILM.

Hubing et al. (2002), in searching for effective instructional strategies that would solve at least some of the problems involved in the learning of engineering modules, considered multimedia instructional aids as a means of facilitating learning. The authors introduced the use of computer-based animated interactive learning courseware, into the learning of the mechanics of materials course in mechanical engineering classes. These were introduced as classroom lecture supplements. They feature animations, graphics, and interactivities that are designed to engage and stimulate students, that effectively explain and illustrate course topics, and that help the students to develop problem-solving skills. The authors found that the use of the computer, as a medium for instruction, provides many learning capabilities that cannot be readily duplicated within the traditional lecture format. However, the teaching method still followed a traditional approach.

In a more recent study on the use of multimedia to facilitate learning, Marek and Aleksander (2005) made the point that some topics in the manufacturing processes course in the department of mechanical engineering were very complex and difficult to explain. In this type of situation, where teaching is impaired even at the best of times, learning becomes almost impossible. Marek and Aleksander found the use of computer animation and simulation as a teaching aid to be a more effective instructional strategy compared with the use of traditional teaching approaches only. They found that the students' performance improved by about 15% when this intervention was implemented. Furthermore, these two researchers believe that animation helps to convey the intuition behind the phenomena in that it permits the presentation of complex processes without the need for mathematical equations.

Cleghorn and Dhariwal (2010) proposed and tried out the Multimedia Enhanced Electronic Teaching System (MEETS). According to these authors, MEETS has proved effective in the teaching of large core mechanical engineering undergraduate modules. MEETS uses two high definition document cameras to project handwritten notes, illustrate mechanical drawings as they are created, and demonstrate small mechanical systems. The advantage of this method over the previous traditional teaching and learning approach used in the university where they work is that MEETS uses the advantage of a personal computer to facilitate the use of conventional transparencies.

According to the author, comments from some of the students who participated in the study revealed that this instructional approach was preferred, because it made it easier to conceptualise and learn the mechanical engineering core modules (Cleghorn & Dhariwal, 2010). The mechanical engineering department of the university where the study was carried out has since adopted MEETS as its instructional method for teaching large classes (Cleghorn & Dhariwal, 2010). However, my own observation is that, again, MEET uses a traditional teaching approach. The instructional aids used in the study by Cleghorn & Dhariwal (2010) only help to enlarge the lecturer's prepared notes. It facilitates note copying, but not learning itself. A better teaching and learning approach is needed to teach the large classes that were the focus of Cleghorn and Dhariwal's concern. Note that the CCAILM learning model is structured to meet the leaning needs of both small and large classes.

Some schools of thought, such as those discussed above, are deliberately turning to modern technology for solutions to the recent problems encountered in the learning of engineering modules. Others, however, such as the following, are concentrating on developing new learning theories, and on improving the existing learning or instructional theories to fit present-day situations in engineering classrooms.

Taraban, Anderson, Definis, Brown, Weigold and Sharma (2007) built on prior research studies undertaken by Taraban, Hayes, Anderson and Sharma (2004 & 2005), which reported that students devoted more of their study time to developing problem-solving skills – to the detriment of increasing their conceptual knowledge of the subject. Taraban et al (2007) believe that learning is promoted when students learn in a rich learning environment, in which they learn from visual, auditory and printed environments, and where problems are solved through the use of instructional software. Taraban et al (2007: 58) claim that "these kinds of learning materials were consistent with theories of skill development, which demand that students be provided with relevant factual knowledge and the means to transform that knowledge into skills through applications to problems".

Among other findings from the study of Taraban et al.(2007), it became clear that students demonstrated striking individual differences in the way and the extent to which every individual cognitively employed each of the learning materials. However, and in contradiction to Taraban et al.'s aim, which was to provide the students with relevant factual knowledge, the CCAILM learning model proposed in this research report encourages and motivates students to construct and discover their own knowledge.

Felder (1995) reported that one way of increasing active teaching time is by giving students more exercises, thus encouraging greater participation from students themselves. On the basis of this claim, She and Looney (2010) introduced a learning strategy to facilitate students' active learning in mechanical engineering in the strength of materials module. The new learning strategy, which is meant to facilitate active learning, involves mixing lecture and tutorial classes in a single lecture time. The first 20 minutes of the two-hour lecture time is to be spent on lecturing, while the remaining 100 minutes are allocated to tutorials.

The authors explained that the instructional strategy of the lecture session was to encourage students' participation by questioning students who, in turn, could pose questions of their own. The tutorial sessions involve grouping students into units of three or four; the students then attempt to solve tutorial questions step-by-step, working as a group. Group work encourages students to develop team skills, and simultaneously builds cooperative learning skills. According to the authors, students prefer this learning approach to traditional lectures and tutorials.

Cole and Spence (2010) showed how the challenges confronted in teaching a large first-year fluid mechanics course were overcome and how students' engagement in the classroom was encouraged. They proposed that normal traditional teaching be interspersed with active learning. This learning approach involves giving students short questions/puzzles to think about during the lecture. Throughout tutorials, students are divided into smaller groups of about 25 - 30 students; each tutorial class ends with a 10-minute test. The marks obtained from the test contribute 20% towards the final course mark.

The teaching approach described above is very similar to Skinner's S-R Operand Conditioning learning theory (Skinner, 1950). The assessment was designed to encourage and maintain the student's involvement in the course. The student's target (response) was to perform above average in the test (stimulus). Klein (1991) categorised learning through response and stimulus as appetitive learning.

Brose and Kautz (2010) looked at changes in the instructional setting in engineering classes. They proposed that active learning techniques be combined with instructional materials developed on the basis of students' specific misconceptions and misunderstandings with a view to addressing these misconceptions. The study entails identifying students' misconceptions and misunderstandings, developing worksheets that contain all the misconceptions and misunderstandings obtained from the students themselves and, lastly, using the worksheets in collaborative group tutorials. Brose and Kautz are of the opinion that the use of the new learning material, in an active learning environment, has shown signs of significantly improving student outcomes.

However, the efforts of engineering education researchers, some of which are discussed above, to facilitate students mastery of engineering modules, and improve the competency of engineering graduates to meet the standard of industrial demands, are still lacking an instructional strategy. Such a strategy should offer real solutions to the multifaceted problems that beset engineering education globally.

The CCAILM proposed in this report for the teaching and learning of engineering modules is characterised by learning through doing, rather than learning by hearing (Petruska, 2010). In addition, it is also characterised by constructing knowledge that can be seen and critiqued, thus helping in the construction of mental knowledge (Paper, 1993) – with the help of modern technological learning aids. Engineering education, which is more of a practical application of theoretical concepts, should harness the potential of modern technology in knowledge construction (Mayer & Moreno, 2002).

The CCAILM learning model

As mentioned earlier, studies have shown that traditional lectures still predominate in university classrooms (Bonwell & Eison, 1991; Saroyan & Snell, 1997; Gallagher, 2000; Faleye & Mogari, 2010). The instructional procedures found in traditional teaching and learning classes are dominated by the lecturer. The lecturer puts a lot of effort into helping students acquire information that is deemed an essential part of the knowledge base. Only a small proportion of the lecturing time is devoted to helping students make sense of this new information and connect it with relevant, prior knowledge in a way that leads to the student understanding what he or she is being taught. In addition, less time, if any, is devoted to helping students learn how to apply the theoretical concepts to real-life experiences. Instead, conceptual understanding and the ability to practically apply concepts are left for students to accomplish by themselves.

However, Shuel (1988) views learning as an active, constructive and cumulative process. This means that learning with understanding should involve instructional strategies that will make students actively participation in the classroom, as they construct new knowledge and relate this new knowledge to relevant, prior knowledge. Classroom instructional strategies are needed that will encourage conceptual understanding.

In view of the foregoing, the author of this research report proposes that the CCAILM learning model be used in engineering classes. The constructionist learning theory, the media-affect-learning hypothesis and the multiple representation principle were used in developing the CCAILM learning model. Each of the components of the CCAILM learning approach is expounded below:

- The constructionist learning theory emphasises the construction of knowledge mentally and physically (simultaneously), and then presenting this knowledge for criticism and acceptance by others (Papert, 1991). This includes discussion within a group. Students are to think about the new knowledge, link it with relevant, prior knowledge, and demonstrate their construction of new knowledge (either by a diagram or drawing) while working together with other members of the group.
- The media-affects-learning hypothesis states that advanced instructional technologies promote in-depth learning (Moreno & Mayer, 2002). The use of technology in teaching and learning facilitates the understanding of abstract concepts by presenting such concepts in 3-D form (as if it were a real-life situation).
- The multiple representation principle states that it is better to present an explanation in words and pictures rather than solely in words (Mayer & Moreno, 1998). This is based on the fact that humans have separate channels for processing different information modalities (e.g. visuals, auditory and tactile) (Baddeley, 1992). The idea here is that the information may be represented and organised in two representative codes – verbal and nonverbal (Paivio, 1986). Meaningful learning occurs when the learner spends conscious effort in cognitive processes such as selecting relevant new verbal and nonverbal information, organising it into coherent representations, making referential connections between the representations, and integrating these representations with existing knowledge (Mayer & Moreno, 2003).

In view of the components of CCAILM discussed above, the author's hypothesis is that "if students are taught by means of a technological learning aid, and if CCAILM instructional strategies are followed, so that students demonstrate their internal knowledge construction physically as they engage with their peers in discussion, a deeper and permanent understanding of the subject matter will result". Figure 1 shows the structure of CCAILM.

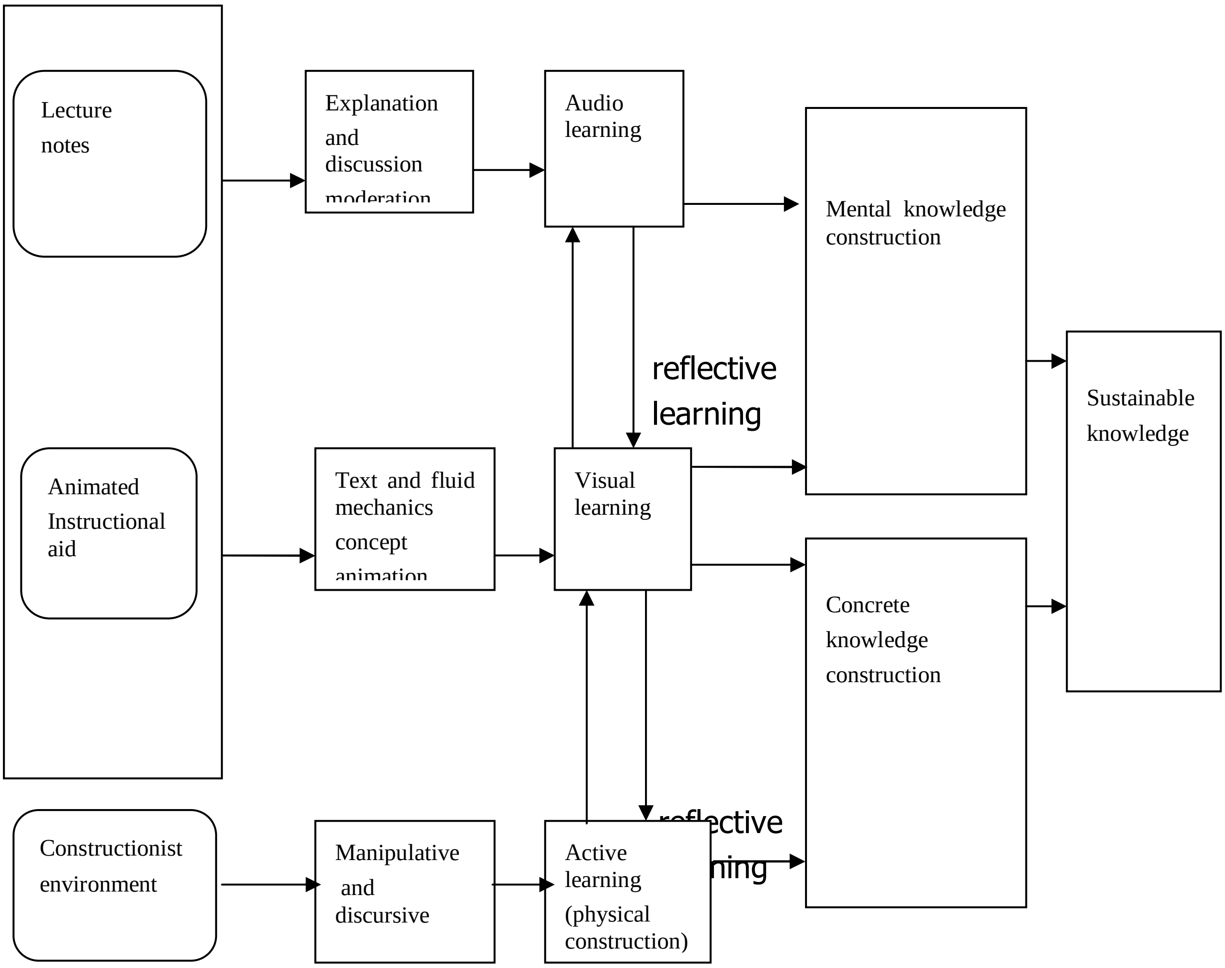

Figure 1 CCAILM – structure

Figure 1 shows the process of conceptual knowledge construction that takes place when students are taught using the CCAILM learning approach. The details of teaching and learning activities involved in CCAILM are discussed below.

CCAILM instructional strategies

There are four teaching and learning instructional phases proposed in the CCAILM learning approach: introduction; knowledge construction; class discussion; and the problem-solving phase.

1. Introduction phase

The lecturer ensures that every student belongs to a classroom learning group to facilitate group discussion (from the outset, at the beginning of the semester, the lecturer divides the students into classroom learning groups). At the beginning of the lecture, the lecturer asks a few questions on the previous concepts learnt. S/he then displays his lecture notes on the white screen, which contains the new concepts, definition, theorem, etc., to be learnt. After a brief introduction of the topic and the new concepts, the lecturer displays the computer animation relating to the topic/s concerned.

2. Knowledge construction phase

The lecturer poses a leading question, such as "what do you understand by………?" or "explain…………", to the students. This type of question will "kick-start" individual and group discussion. The lecturer allows the students to construct individual meanings of the new concepts. The animation of the concept under discussion is left running, so that students can continue to refer to it for clarity of ideas and to facilitate new knowledge construction. The lecturer moves round all the groups in the class, in order to moderate the discussion in each group.

3. Classroom discussion

The lecturer requests each group to verbally respond to the questions asked earlier on. Students are allowed to present the findings and views of each group, while other students listen. The student answering the question may explain and demonstrate verbally, and may also use objects or diagrams to demonstrate individual or a group's cognitive understanding of the new concepts. The explanation given may be supported or rejected by other students in the class.

4. Problem-solving

The lecturer displays a problem on the day's topic on the white screen and allows students to solve the problem by working in groups. The lecturer moves among the groups in order to monitor how each group is tackling the problem. Any of the group could be called upon to make a presentation to the class and answer questions. The lecturer asks students to suggest other possible applications of the concepts learnt to real-life situations. In addition to the suggestions from the students, he may give a real-life situation, in which the new concept will be required. Finally, the lecturer gives the class homework that will be presented in the next class.

The CCAILM instructional steps are summarised in the table below.

Table 1 The instructional steps in CCAILM

Instructional phase	Lecturer's activities	Students' activities
Introduction	Presents the topic and the new concept on the white screen. Uses questioning to survey students' prior knowledge.	Students are seated in groups where they can freely discuss ideas with the fellow students. Relate new concepts with previous ones.
Knowledge construction	Explains briefly the main features of the new concept. Displays the	Based on the new concept, form views and ideas on the

	computer animation of the new concept. Encourages cross-fertilisation of ideas, views and information. Moderates lecture room dynamics.	basis of logical reasoning, use information to construct public entity of the concept. Refer to the running concept animation to facilitate knowledge construction. Give real-life representation of the constructs. Share views and ideas with other students.
Class discussion	Allows each group or individual to present ideas, views and constructs to the whole class. Encourages comments and criticism from other students; makes a summary of the main ideas and constructs in a way that makes logical sense.	Present individual or group views, ideas and constructs to other students. Identify weaknesses in other people's opinions. Criticise each others' views and constructs. Keep track of the lecture. Comment, summarise and evaluate initial conception, using new constructs and ideas.
Problem-solving	Presents students with real-life problems for them to solve. Moderates the answers or ideals in an attempt to solve the problems.	Apply the concepts, ideas and new constructs to solve the problems posed.

Implications of CCAILM for engineering students and lecturers

The instructional strategies in the CCAILM learning approach are designed in a way that minimum amount of teaching will lead to extensive learning on the part of the students (Papert, 1991). In the CCAILM approach, the lecturer introduces the topic, while the students construct their knowledge with the help of an animated learning aid, peer discussion and lecturer guidance. This means that the problem of teaching large engineering classes is effectively solved: the lecturer only needs to facilitate the process of knowledge construction by visiting each group as they engage in discussions. The CCAILM teaching and learning environment has the potential to offer students more learn and achieve deeper conceptual understanding. Students learn through classroom discussion, and by exploring and presenting their findings (Shuel, 1988). Furthermore, this approach also makes it easier for students to learn difficult concepts.

This research report also emphasises the implication of Papert's constructionist learning theory in the mastery of engineering modules. Constructionist theory forms one of the principal components of CCAILM learning model. CCAILM stresses the point that knowledge constructed mentally, supported by animation learning aids, and represented physically tends to be permanent; it leads to a deeper understanding of the subject and, indeed, improved academic achievement. This has been proved in two separate studies (currently under peer review).

CCAILM: implication for engineering education curriculum planner

The curriculum is the formal process through which educational aims and objectives are achieved. This process includes two prime factors: learning and instruction. Bruinsma and Jansen (2007:26) remark that, in an ideal situation, the curriculum is designed according to the principles of learning and instruction.

The *Australian Ballarat Diocese* (1989:3) is more explicit in its definition:

> The term *curriculum* concerns all the arrangements the school makes for students' learning and development. It includes the content of courses, student activities, teaching approaches, and the ways in which teachers and classes are organized. It also includes decisions on the need for and use of facilities.

The current instructional strategies used in the teaching of engineering modules in South African universities, where the lecturer comes to class to read out his or her lecture notes and solve one or two problems on the chalkboard (Faleye & Mogari, 2010), clearly calls for change. It is, therefore, imperative that the engineering curriculum be adjusted to accommodate the instructional steps proposed by CCAILM.

It is, of course, true that the current, traditional instructional strategies make it possible to complete the engineering modules scheme of work more quickly compared with the CCAILM learning strategies (which require that each student construct his or her own knowledge, which then has to be critiqued by other students in the class). In addition to this, the current teaching method is lecturer-centred. CCAILM, on the other hand, is a student-centred approach that needs more lecture-time. The pace of the lecture is decided by the students, while the lecturer moderates.

In the traditional teaching and learning approach, the lecturer rushes to finish the topics included in the curriculum, with little regard for the students' cognitive understanding. According to Ramsden (1992), the approach to teaching is an important component of teaching that influences students' performance at university level. When a lecturer has to rush to get through a set of topics, this will definitely affect the performance of his or her students. Given the foregoing, a curriculum is needed that supports the implementation of the CCAILM learning approach.

Again, the standardised assessment method in the traditional learning approach makes it possible for students to memorise in order to pass tests and examinations, without having any conceptual understanding. The author of this report proposes that the assessment procedures in CCAILM should avoid the standardised assessment techniques that favour memorising. Instead, the assessment should focus more on how students can demonstrate adequate knowledge in their practical application of the concepts. Assessment should also be made part of the learning process, so that students can play a bigger role in evaluating their own progress.

Conclusion

As mentioned earlier on, various efforts have been made to find an appropriate teaching and learning model that will facilitate an in-depth and permanent understanding of engineering concepts (some of these attempts were reviewed in section 2). The new CCAILM learning approach is another attempt to formulate an appropriate teaching/learning approach that will meet the learning challenges in today's engineering classrooms. The CCAILM learning approach has proved to facilitate learning (in a large mechanical engineering classes) and, in another study, has been found to improve students' achievement in fluid mechanics in mechanical engineering classes in some South African universities (the two studies are under peer review). The CCAILM approach is, therefore, proposed for the teaching and learning of engineering modules.

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