"Actively constructing interactive engineering learning environments"

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Abstract

Across the spectrum of engineering, science and mathematics education, recommendations have been made for the inclusion of active learning through the use of more innovative classroom activities. These activities should be aimed at engaging students in the learning process for increased achievement gains. Engineering education researchers have suggested, for the last twenty years, the benefits of implementing active learning approaches to engineering learning environments since various studies have found the achievement gains have significantly improved when students take a more active role in their own learning [1]. However, there exist diverse interpretations and discussions around the idea of what active learning means as well as the types of teaching and learning approaches that have been utilized by engineering faculty aimed at including active learning in their course delivery. In a comparative literature review [2], it was discovered that there are significant differences in what has been understood and applied in science classrooms as active learning. Consequently, Chi [2] developed a framework of learning activities aimed at highlighting the different types of learning activities that are and can be included in classrooms for maximized results. Building on the work of Chi [2], this paper seeks to explore the implementation of active learning activities in engineering learning environments. This synthesis of literature on active learning in engineering classrooms will highlight conflicting views on what counts as active learning, identify examples of active learning strategies that are currently being used and where they fit in the active-constructive-interactive framework as well as suggest innovative approaches that may be applied to engineering classrooms without much required change to the overall content delivery.

Background

Across the spectrum of engineering, science and mathematics education, the case has been made for the use of more innovative ways of teaching with the aim of actively engaging students in the learning process for increased achievement gains. Engineering education researchers have suggested, for the last twenty years, the benefits of implementing active learning approaches to engineering learning environments since various studies have found the achievement gains have significantly improved when students take a more active role in their own learning [1]. In traditional engineering classes, the mode of instruction is usually of the kind where the students are passive participants in the learning process. The instructor is the “sage on the stage” [3] while students basically go through the motion of listening and taking notes. However, many recommendations have been made to include student-centred activities or learning environment designs to overcome this status quo as it has been posited that students learn more when the environment is conducive to their active involvement [4].

Constructivist theorists have purported the learning process should be so structured that students are encouraged to employ real thinking and by extension engage themselves actively in their own learning. The implication for instruction based on their view is that the learning environment should be more learner-centred than teacher-centred [5][6]. With the considerable attention given to active learning, much work has been done through the implementation of a wide array of active learning approaches such as problem based models, inquiry-based, cooperative and
collaborative learning, various methods of inductive strategies, as well as discovery learning measures [7]. Basically, the main posit of active learning is to increase student participation and engagement through the use of concrete learning activities aimed at knowledge construction in which students interact with the material and on some level each other.

Conflicting views on what is active learning

Researchers have theorized that though educators have discussed and established the benefit of employing active learning models to the initially passive learning environment, not much clarification has been made to what really counts as active learning [8]. In discussing being active [2], it has been highlighted that active learning indicates that something is being done and through the process of doing, or completing a task, or becoming engaged with the learning material, through direct interaction, learning occurs. Active learning is defined as the process by which students do most of their own work in the act of acquiring new information. In an active learning environment, students are encouraged to physically engage in studying ideas, problem solving and ultimately applying what they have learnt. Learning then is such that it involves more than the mere acquisition of knowledge. In fact when learning, students should be afforded the opportunity to touch, see, hear, feel, ask questions and have discussions with each other about the one concept. In responding to the call made about the moving away from traditional lectures and passive knowledge acquisition when the instructor is the “sage on the stage” [3], engineering professors have endeavoured to create learning environments with the hope of making students excited about the material and by extension more receptive to learning [9].

Active learning involves the engagement of students where one of the key components is encouraging interaction among participants [8]. It is discussed that active learning, through siloed activities, on the part of the student is not by itself very productive if students do not have the opportunity to interact with each other. Similarly since cooperative and collaborative learning has been the most promoted aspects of active learning, researchers have suggested the importance of students working together with the intention of creating new knowledge and engaging with the material while building a community of learners [1]. The classroom design, as stipulated by the active learning approach, would involve the use of small learning groups, whether formal or informal, in which each student’s opinion is treated as equally important. In this model of active learning, classroom activities are aimed at problem solving under the social interdependence theory. According to this theoretical approach, the group operates as whole in which the action of each individual determines the overall outcome of the group as well as its ability to achieve the preset goals. Ultimately, active learning in this space dictates the interaction of students with the material and each other so as to increase their learning.

In contrast, active learning has been described as the process by which students engage in activities which causes them to reflect on their own learning [5]. Students are thereby forced to think about how their level of participation or contribution to the learning process affords them the ability to improve their mental and physical learning of the concept in a desired manner. In this student-centred approach to instruction, the instructor provides students with the opportunity to engage actively while learning independently from one another through the gathering of information, thinking and problem-solving activities they are expected to complete whether in class or at the end of instruction. Activities are usually of a problem-based nature and students
are encouraged to incorporate critical thinking and reasoning skills which can lead to “increased motivation to learn, retention of knowledge as well as a deeper understanding of content” (p. 160). It is through the application of such activities learners actively constructing their own knowledge which is more than they would have done in the classic lecture approach usually applied in large engineering learning environments. Learning has also been discussed as the fruitful individual activity whereby when students are provided with the opportunity to construct their own learning about concepts ultimately their learning gains will increase whether or not they interact with others \(^\text{[10]}\). Active learning is therefore categorized by how much responsibility the student is encouraged to take for their own learning and what activities they engage in as individuals who may or may not have any interaction or collaboration with the learning community.

Based on these studies, the term active learning is highly subjective to the individual or individuals implementing it and under what conditions this approach is implemented. A comparative literature review done by Chi \(^{[2]}\) found that there was severe misuse and general misunderstandings of the term “active learning”. It has been discussed that the very act of engaging in one’s learning could be considered active engagement however what really makes the difference in students’ learning and understanding of the material is the use of various learning activities along a taxonomy discussed in her active-constructive-interactive learning framework \(^{[2]}\). The findings from the study of relevant literature indicate the three terms: active, constructive and interactive were at times used interchangeably though the activities that reflects each term when applied to learning environments were extremely different. It was found that the achievement gains were higher when students engaged in interactive activities over the use of constructive activities. In addition, constructive activities had better results than active activities which in turn were higher than passive activities.

The literature included in this qualitative synthesis is aimed at building primarily on the work or Chi \(^{[2]}\) and Menekse et al. \(^{[11]}\). The articles to be used are selected based on their relevance to the active-constructive-interactive framework as well as their obvious relation to engineering learning environments and engineering or science concepts. In addition, since the current focus on engineering learning environments involves the use of innovative and engaging learning activities these articles are also selected along those lines. The purpose of this paper is not to highlight the conflicting views on what active learning is but to explore the three facets of this active-constructive-interactive framework \(^{[2]}\) in order to investigate what work has currently been done in this space and what areas for further work are present. Consequently, in the remaining sections of this paper the active-constructive-interactive framework will be discussed in separate sections and supporting studies relating to each area will also be explored.

Chi’s active-constructive-interactive framework

This framework was developed using a learner-centred approach in that its aim is to explore learning outcomes as a consequence of the activities that students are expected to engage with. Therefore, the main idea for this approach is to highlight the learning activities that best suit each area; active, constructive or interactive, rather than the classroom learning environment itself. While the activities themselves would inform the design of the learning environment, engineering faculty could basically adjust their mode of course delivery through the inclusion of
learning activities without having to feel like they have to do a complete overhaul of their classes. Common of these activities requires students to talk, discuss, write and apply what they are learning outside the scope of rote learning such as memorization and application. In a follow-up study to Chi’s work, it was discussed that broad cover which is applied to all the classroom activities used to engage students as active learning lacks the ability to highlight the different cognitive abilities that are related to each facet of the framework \[7\]. Since the overall function of the framework was to prove what activities were better at eliciting increased student understanding, it is therefore logical to categorize learning activities and the level of cognitive engagement required such that learning outcomes are maximized.

The term active by definition suggests one is physically doing something. Hence when applied to learning it can be characterized by having student involve themselves physically while learning. In this case, activities that would reflect the active aspect of the framework include students engaging in the process of learning within the scope of the instructors expectations. Examples of such activities are “reading, highlighting or repeating sentences, copying and pasting some of the text, looking and searching for specific information in a text” (p. 4) \[7\]. In its simplest form being active indicates the overt physical activities students do which on surface level does not require the application of much cognitive thought. While it requires on some level an action on the part of the student that would not have been otherwise required in a passive learning environment, active level activities leverages existing knowledge hence students are typically paying more attention as well as learn better in this learning process than the students who are passive.

The constructive facet differs from active in that when students engage in activities of a constructive manner they are actually developing knowledge through the creation of outputs that tends to go beyond their existing knowledge or understanding. Whereas an active overt activity would require students to merely highlight a given sentence, in the constructive realm they would explain their understanding of the sentence and in so doing further develop their understanding of the material. Overt constructive activities such as “drawing a concept map, asking questions, taking notes, comparing and contrasting cases and integrating text” \[2\] moves beyond the simple physical activities as stipulated by active activities. Consequently, the use of cognitive thought is higher when engaged in constructive activities in that students are now inferring new knowledge based on the material they have been interacting with and their own existing knowledge that is, at this point, being modified to accept this new knowledge. Conceptual change theory aspires to the use of these types of activities in the learning process as the idea of conceptual conflict being experienced due to the disconnection one would experience seems like a plausible agent for eliciting knowledge.

The most engaging of the three, interactive activities, requires students to not only interact with the material but with each other as well. This facet involves the construction of knowledge but differs from constructive activities in that the student does not engage in interactive activities alone. With these types of activities, students work together in building new knowledge in an environment where each person’s idea is treated as important and contributes equally to the overall consensus of knowledge creation. However, Chi \[2\] cautions that not all group work qualifies as interactive activities and one student self-explaining a concept while the other listens and analyzes does not constitute an interactive activity. In addition, interactive activities are also
categorized by student interaction with the instructor. Examples of such activities are “working in teams, peer teaching, interacting with feedback from the teacher” (p. 81).

In a study into how the differentiated activities associated with each construct of the active-constructive-interactive framework would affect student learning in an introductory materials science and engineering class, the use of one type of activity per class period was employed so as to be able to test for the learning associated with each type of activity [11]. The students were tested after each class period in order to ascertain their learning from the in-class activities. The quizzes included both multiple choice and open ended items, this was done so the researchers could gain insight of students’ depth of cognitive thought. The findings from their study gave evidence to the hypothesis made by Chi [2] that constructive activities offer more achievement gains than active activities and that interactive activities elicited the most gains than constructive or active activities. This article portrays how this framework can be incorporated in engineering learning environments for maximum results in improved student learning outcome. However the authors cautioned to the generalizability of this study to other contexts. This paper will present how the active-constructive-interactive framework has been employed by engineering faculty in their existing engineering learning environment designs under the broad heading of active learning and what achievement gains have been reported.

Active learning activities in engineering learning environments

Based on the definition active learning activities in the Chi [2] taxonomy, any overt physical learning activity qualifies as active. Traditional lectures have been discussed as being less effective at garnering the retention of information and so one of the approaches to encouraged students to not only pay attention but to ensure some level of attendant action is through the use of guided notes [12]. Guided notes are information sheets prepared by the instructor in advance and given to the students at the beginning of the class. These sheets consist of incomplete information relating to “essential concepts, ideas, graphs, problems to solve and conclusions” (p.16). This activity of encouraging students to work at completing prepared unfinished statements related to the information being presented in the class is best suited for classes of large sizes. Guided notes have an advantage over the traditional act of note-taking in that as students are expected to complete the statements they are forced to pay attention to details in the classroom as oppose to merely “recording all the presented information without critically judging the importance of specific content” (p. 16).

This approach is discussed as being very effective in engaging students as they are forced to pay attention throughout the delivery. Since this measure requires very little cognitive effort on the part of the student as they are merely filling out the blank statements, on the primary level students are “doing” something which is the definition of active activities. The introduction of active learning strategies in lecture setting where small group work might not be feasible depending on the class size can significantly improve students’ ability to recall information as well as increase their engagement [9]. In this case, active learning is classified by what the student does and thinks within the scope of the class setting. In a novel teaching approach applied used to engage students in a lecture class, the instructor encourages the use of an online learning application prior to each class where students are expected to search for class material and preview the material and then respond to simple inquiries about what they read [13]. This gives
the instructor the ability to adjust where necessary the class content based on student concerns. In this strategy, the class session can better maximize what concepts such are focused on and how well the students engage themselves since the class would have been formatted to reflect their level of understanding.

It has also been discussed that while much attention has been paid to the use of active learning approaches in lecture class, laboratory classes themselves have some measure of passive engagement that requires the application of active activities\textsuperscript{[14]}. The use of laboratory manuals with step-by-step discussions of how to conduct experiment causes students to learn concepts by rote. Researchers suggest the inclusion of components of the lab activities into lecture materials and having students being required to apply the formula they would be given in the lab to the activities they would engage with in the lecture class. In doing this students would be better able to connect what they are learning in the lecture class with the lab activities. Linking lab and lecture provides students with the opportunity to practice what they learn as a collective process as oppose to disconnecting the two areas. In addition, the use of technology in support of creating active learning activities within the engineering classroom has been known to have remarkable benefits\textsuperscript{[15]}. In this classroom, teacher and students all have a Tablet PC called the Classroom Presenter. The advantage of using the tablet is that all the students electronically received the slides, respond to the prompts on each slide, complete the given activity and send their responses back to the instructor. Using this approach students receive real time feedback and as such are able to adjust their modes of thinking. This act or incorporating students direct contribution to the learning environment in the class has been reported to have significant gains in the students’ overall achievement as well as it provides a measure of ensuring that students continue to actively participate in the class without having to exert too much effort in the process. In addition, students’ misconceptions can easily be addressed in the class based on their responses to the prompts.

Constructive learning activities in engineering learning environments

Following the constructivist approach to learning the general belief is that learners must be engaged on the construction of their own knowledge which goes beyond the idea that knowledge can simply be transmitted from teacher to learner. Any instruction using the constructivist approach has the potential to lead to meaningful learning and understanding based on the fact that students are able to fully engage and take ownership of their learning\textsuperscript{[16]}. Research in learning from a constructivist approach suggests that meaningful learning takes place when students are given the opportunity to actively construct their own knowledge by using their existing knowledge to make sense of the new material they are engaging with. Learning is itself an active process in which active knowledge construction within a specific context contributes to advance thinking which in turn causes high quality knowledge acquisition. The most appropriate learning environment that stimulates knowledge construction and the acquisition of problem solving skills would be problem-based in which students are engaged in solving problems of a real-world nature\textsuperscript{[17]}. In addition, it has been explained that constructive learning activities encourages students to take ownership of their learning which leads to deep learning stemming from the psychological and emotional involvement they invest in the process\textsuperscript{[18]}. Constructive activities include open-ended problems in which students are expected to process information, solve problems, and investigate different approaches and solutions\textsuperscript{[19]}.  


In engineering, the objective is to have students who possess the ability to create solutions to problems for which they have a lack of sufficient knowledge. Consequently, learning environments should emphasize the importance of being able to develop conceptual frameworks as well as the ability to make meaning of problem-solving activities. One such learning environment uses simulation type software, a specific program called Technology Enabled Active Learning, which when incorporated in large undergraduate physics courses afforded students the opportunity to learn about electromagnetic concepts through game playing and experimentation activities. This hands-on approach to learning about electricity required students to set up experiments of an exploratory nature, using real laboratory components as well as virtual experimentation to conduct specific tests on the apparatus. While conducting the experiments, students were required to respond to thought provoking questions intended to provide them with insights into the result they were obtaining and to relate what they had experienced with their own prior knowledge or experience.

In a similar study, an experiment was conducted in a fifth grade class with eleven year old students about biological reproduction. Students were randomly assigned to either a constructivist-oriented instruction group or a traditional teaching group. Students in the constructivist-oriented instruction group were engaged in activities such as the watching of videos related to methods of plant reproduction that required them to observe phenomena around them, conduct research in order to determine meaning of said phenomena, negotiate meaning, make decisions about what information to accept or reject based on evidence and in so doing construct their own biological knowledge. The method of inquiry with these students required them to engage in information processing activities and to think aloud as they completed the given activities. At times the instructor would ask probing questions to get students to uncover their cognitive processes at certain instances in the process. At the end of the study, students were tested using the same instrument as those in the traditional instruction group. The test item consisted of open-ended items which were intended to measure students’ use of deep thought when answering the question.

Based on students’ responses to the items, it was found that the students in the constructivist-oriented group used more comparative and inferring language when they explained concepts as opposed to the students in the traditional group which did not seem to use deep cognitive thought in answering the questions. The traditional group students basically repeated the information they had been exposed to in their instruction. This finding proved that students who were taught using a constructivist approach had well organized learning structures as the activities employed in the classroom were better at facilitating connections between new conceptions and pre-existing knowledge within the students’ cognitive structures and hence promoted better performance on the assessment instrument. Students who engage in constructive activities would then have better retention of the material since as they engage with the information and apply their own meaning through the activities they are required to conduct they commit this new knowledge to their long term memory.
Interactive learning in engineering learning environments

Interactive activities, the most engaging of the three types of activities in the framework, are discussed as the most beneficial in eliciting student engagement and learning. According to active learning researchers, students learn more not only when they active engage in the class and with the material but more so when they interact with their peers and instructor [1][22][23]. When students interact with each other to complete activities related to scientific concepts, misconception are easily uncovered and address since they are no longer working in silo but actually contributing equally to the process of learning. This concept of using interactive activities, building off the interactional model of classroom teaching and learning, explores the various activities students can be encouraged to engage in with the hope that by their interacting with material and each other they would show increased cognitive gains [24].

The use of conditions of instruction which promotes deep approaches to foster active and long term engagement in learning tasks and class information with the hope of increasing conceptual understanding are more profitable when the interactive component is included [6][15]. Human beings, by nature, are socially inclined and as such learning is a process by which we interact and engage with each other. In a typical interactive learning environment students are building mental models around the new material that is being learnt however, individuals are more likely to learn more when they learn together rather than learning alone [5]. This author discusses the benefits of self-explanation with emphasis being placed on the fact that as students explain their own thoughts to others they are forced to reconcile conflicting ideas and in the process of doing so meaningfully learning occurs. Additionally, suggestions for active type instruction that employs the use of interactive activities such as inquiry based and discovery learning emphasizes interaction with peers and instructors where feedback is readily available and gives students consistent opportunities to apply their learning in the classroom have also been made [25]. This kind of learning activity shifts the focus of the classroom from mere teaching and learning to promoting a learning environment where students are able to develop the relevant metacognitive skills necessary to become independent and critical thinkers.

In a study conducted in a science class with the use of personal response systems, commonly called “clickers”, it was reported that students’ conceptual understanding of the concepts presented in the class increased after they were allowed to have discussions with their peers [26]. In the classroom students were presented with a question and required to use the “clicker” to indicate their answer choice. A histogram was used to project the responses to the class. Following the projection of response, the students were allowed to discuss in small groups and were then presented with an isomorphic question. Findings from their study indicated that students’ conceptual understanding significantly increased after the discussion with their peers even if the group did not collectively have the correct answer. This study proves that peer discussion and interactively engaging with others in the classroom not only enhances learning but provides students with the opportunity to arrive at solutions together. In addition, the authors discuss that this approach can be applied to the traditional engineering lecture class where the size of the class does not allow for the forming of structured formal cooperative groups. Students can still be interactively engaged without much disruption caused within the class.
Another approach to the inclusion of interactive learning activities in the classroom can be through the use of innovative instructional software which requires students to read materials from the computer screen, listen to narrations, interact with the simulated activities as well as solve presenting problems. A study was conducted with undergraduate engineering students in a thermodynamics class in which one of their research questions was to assess the difference in the use of cognitive processes that students use in different learning contexts especially those related to reading of text, interacting with others as well as when problem solving. In this study, the use of an interactive problem solving model was employed. Students were presented with text they were expected to read and complete an activity at the end of the module. Throughout the module they were expected to think aloud as they navigated through the information. It was found that the level of engagement and use of cognition was highly dependent on the types of activities that the students were presented with. The findings from this study indicated that when students engaged with each other while solving problems their cognitive activity was at its highest use. By themselves, the students would merely paraphrase the information while drawing on phrases and words from the text, however when they had other students included in the discussion the students would employ more self-explanation measures and attempt to make connections between pieces of information by making inferences and posing questions. This, therefore, ascribes to the description of interactive activities along the continuum of the framework in that interactive activities require the highest level of cognitive processes whereby students build new knowledge based on their own existing conceptions and through the interaction with others.

Implementing the active-constructive-interactive framework in engineering learning environments

Interestingly, in the literature there has been evidence of the use of the active-constructive-interactive framework in engineering learning environments however it has mostly been covered under the broad heading of active learning. There have been instances where either type of activity was used in silo but referenced as active learning. Essentially, constructive and interactive activities do require students to be active according to Chi’s definition. Therefore it could be argued that active activities forms the basis of this framework, however the level of learning required and the measure of cognitive processes warranted for engagement is ultimately what determines what types of activities are used. In addition, previous discussion in this paper has highlighted the fact that the term active learning has been misused as it relates to how professors have assumed to apply it within their classrooms. Some researchers have cautioned against the belief that active learning is the application of group activities within a classroom. The table below compares the type of student involvement, level of cognitive difficulty and measure of achievement gain for each three learning activity in the framework.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Type of student involvement</th>
<th>Level of cognitive difficulty</th>
<th>Achievement gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active activities</td>
<td>Individual</td>
<td>Low</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Constructive activities</td>
<td>Pairs or groups</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Interactive activities</td>
<td>Pairs or groups</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 1 showing comparison of active, constructive and interactive activities
Following the discussion about the inclusion of more active learning models to the engineering classroom, engineering professors have sought to employ more student-centred approaches to learning. In this new approach to participatory learning, students are given more responsibility over their learning and encouraged to take a more active role in the classroom \[1\][6]. The necessary shift in the paradigm of STEM education is required to create learning environments which excites students and encourages exploration and discovery of knowledge \[28\]. Instead, active learning should be considered as student-centred framework which when applied within a classroom, affords students the ability to engage with class material and each other while employing various cognitive processes represented by the level of engagement required by the activities they are expected to complete \[29\].

Learning exists in different settings and approaches that are highly dependent on the activity in which one is engaged so as to acquire such knowledge of various cognitive levels \[24\]. Since it has been discussed that different kinds of activities, active-constructive-interactive, has the ability to elicit different types of cognitive processes \[11\], then the ideal engineering learning environment is the one that incorporates the complete active-constructive-interactive framework. Engineering learning environments should be inclusive of student participation, teacher encouragement, peer-to-peer interactions which are positively related to improve critical thinking. In addition, if the aim of the learning environment is to cause conceptual change when learning about material, the classroom should provide opportunities for existing knowledge to be uncovered and misconceptions repaired. This has been described as best achieved when students work in interactive learning environments \[30\]. Another concern that has been raised in relation to engineering learning environments is the proposition that students should, through their involvement in the learning environment, appreciate the value of learning together and in doing so they would create within the classroom a community of learners \[1\]. Benefits students would garner from this community are along the lines of “stronger thinking and reasoning skills, problem formulation and problem-solving skills, skills for working cooperatively with other as well as skills and confidence for figuring out things in complex environments” (p. 30).

If engineering faculty are desirous creating learning environments or including in their existing classrooms a more student-centred approach where students learn through active involvement such as various methods of inquiry with the intent to make sense of new information then the learning environment must be of such that students are afforded the opportunity to participate in such practices. Since knowledge and cognitive processes are increased when students engage in activities that requires them to interact with each other, which is the main posit of the situative approach to learning, engineering classrooms should employ this approach \[31][32\]. In situative learning environments, instructors endeavor to create a learning community within the classroom in which students are mandated to work collectively when solving authentic assessment tasks aimed at providing them with knowledge while leveraging their real-life experiences.

In a situated learning approach, emphasis is made to bridge the gap between cognition studies and interactional studies. This learning approach encapsulates the benefit of both studies while offering the benefit of having a better understanding how learning occurs and how best to design learning environments. In relation to the active-constructive-interactive framework, this approach offers the best means of incorporating all three types of activities. This is owing to the fact that situative learning emphasizes that the different activities in different learning...
environments are of importance not only because of how effective each type of activity is in teaching content knowledge but also due to the fact that each type of activity dictates some level of participation as a central role in what students learn\textsuperscript{[24]}. That being said, students’ measure of involvement would then be dictated by the type of activity that the material they are expected to learn requires. The situative approach offers a level of dynamic activities in that a learning environment that utilizes this approach gives the students ownership of their learning while still operating within an acceptable amount of guidance by the instructor.

While learning approaches such as problem-based and inquiry based have been discussed as not effective for engineering and science classrooms because the students operate with minimum guidance, their applications in a situative learning environment has been discussed as not only increasing students conceptual gains but also in helping students develop collaborative learning skills\textsuperscript{[29]}. The heavy emphasis placed on learning content, developing self-directed learning skills and solving problems of an authentic nature relates directly to the authentic activities and anchored instruction that are tied directly to situated learning. Similarly, in engineering learning environments students are expected to be able to engage in self-directed learning while reflecting on their experiences in preparation for lifelong learning\textsuperscript{[18]}. One drawback to the implementation of this approach is that students will only involve themselves in the process as much as they feel comfortable to. This is true for any of the three types of activities but more so with the interactive activities that requires them to work alongside their peers. Consequently, instructors have to be mindful of students’ individual differences and help them to see the benefits of engaging in these activities before they are implemented. In this sense, the interplay between the three types of activities in the same classroom would account for this since active and constructive activities do not necessarily warrant any kind of interaction among the students or between students and instructor. However, since interactive activities provides the possibility for the most conceptual gains instructors would have to employ innovative measures of encouraging students to work collaboratively\textsuperscript{[33]}.

Conclusion

Based on Chi’s recommendation that the framework is more a tool for measuring where activities fall along the taxonomy and less of a measure of learning environments, it is fair to say that any particular kind of student-centred learning approach could utilize this framework. The situative perspective was chosen as the literature used in this review incorporated activities that are directly related to this approach when compared to the other theories of learning such as cognitivist or behaviourist. It was also found that while some articles would refer to the activity or approach as being constructive, the authors would mention that students work collaboratively with their peers and by the definition of interactive activities given by Chi\textsuperscript{[1]} and Menekse et al.\textsuperscript{[11]}, any activity in which students engage with the material and their peers or instructor is an interactive activity. In addition, interaction with their peers does not necessarily mean students have to work in groups or peers. By the definition used in the framework, as long as students engage in conversations with each other, whether physically in the classroom or remotely through discussion boards and online environments, they are considered as interacting. The articles that came from computing literature alluded to interaction being through virtual experimentation and discussion as well as with students and instructors while the other discussed interaction as physical activity that warranted the engagement of another person.
In addition, the more classic work done in the space of active learning was beyond the scope of the time frame of the articles included in this review. Consequently, the active learning approaches discussed in this paper were of a more contemporary nature. While cooperative learning is still the most praised aspect of active learning new approaches have been developed but lack the prestige with which cooperative learning is described since these approaches are fairly new and not widely known or applied. Continued work could be done in the space of this active-constructive-interactive framework by applying it to other areas such as science and mathematics as to what would constitute active learning in these areas might be somewhat different from engineering. Although a few articles included in this review came from science journals enough investigation into this and other disciplines has not been done so as to be able to make generalizable statements.

Reference