

Chapter 2: Literature Review on Broad Conceptions of Creativity and their Implications for Fostering Engineering Creativity

Introduction

This chapter reviews broad conceptions of creativity in order to make a case that the ability to generate focused new insights or ideas to solve unconventional problems within engineering education can be enhanced by creating pedagogical conditions where students collectively think about and attempt to improve on existing technologies. It also attempts to capture the meaning variations of creativity in order to compare them with those of the teachers and students as elicited through interviews in the empirical study to be presented in later chapters.

Three broad conceptions of creativity emerge from literature that spans more than 200 years and each will first be reviewed briefly here, to be followed exhaustively in the rest of this chapter. First, creativity is conceptualized as the exclusive province of individuals endowed genetically with special talent and inclination. This position on creativity links creativity with high levels of intelligence, for example, as measured through intelligence tests that calibrate individual Intelligence Quotient (IQ). Given that this position on creativity is located firmly within the creative genius discourses, it becomes inimical that creativity can be learned and enhanced and it thus falls outside the purview of engineering education and this study in particular. Similar studies that link creativity with intelligence include studies on multiple intelligences and artificial intelligence. The Multiple intelligence Theory (MIT) suggests that there are various forms of intelligence that can be found in each individual in differing degrees of strength so that the stronger the specific area of intelligence the more likely that it can develop into creative ability (Gardner, 1983). Artificial intelligence, on the other hand, attempts to advance the mechanistic theory of creativity that suggests that the creative potential of individuals can be enhanced through machine-based algorithmic and heuristic systems of problem-solving (Boden, 1990).

The framing of all these three specific conceptions of creativity that connect creativity and intelligence is set to be cognitivist in nature thus draws largely from cognitive psychology.

Second, over the last two decades and influenced by social and organizational psychology, there has been an increasing recognition that contexts (teamwork) play an important role in enhancing individual creativity. Some creativity research in engineering education locates itself within this framing of creativity. There appears to be some consensus in engineering and engineering education that this framing of creativity is socio-cognitive without making a strong defence of that position. I find this framing of creativity problematic and lacking in theoretical precision because framings of creativity have almost always emerged from the psychology field. Does this mean that the cognitive and social psychologists have developed a new area for the development of creativity outside their entrenched traditional positions? I believe, aware of this theoretical challenge, most engineering education scholars have chosen not to state their theoretical positions explicitly as evidenced by a huge body of engineering education literature on creativity that avoids explicit mentioning of theoretical stances as will be seen from the rest of the chapter. This is unfortunate because studies on creativity development in engineering education could benefit from developing a more sophisticated theoretical frame to shape future research on fostering creativity.

Third, in more recent times engineering education has begun to conceptualize creativity within a sociological framework which emphasizes the development of interpersonal skills as they are essential in situations where creative insights or ideas are generated in a group context and within multiple sites (Törnkqvist, 1998). Key aspects of social creativity that are believed to be essential in fostering creativity in a group context include active participation, joint thinking, passionate conversations and shared struggles often pervasive in meaningful relationships (John-Steiner, 2000). Fischer, Scharff and Ye (2004) add knowledge creation as crucial in collectively generating novel ideas or insights that can lead to the resolution of complex problems.

These authors argue that such knowledge creation entails, among other things, externalization of individual or group tacit knowledge. Individual tacit knowledge involves intuition, judgement and commonsense. Group tacit knowledge refers to knowledge that exists in the distinct practices and relationships that emerge from working together overtime. These issues are taken up in more detail in the next sections of this chapter.

Cognitive Conceptions of Creativity and their Implications in

Enhancing Engineering Creativity

A significant and substantial body of creativity research is framed within the broad cognitive traditions and examines the relationship between creativity and intelligence (Cropley and Cropley, 1998; Cropley 1995; Cropley 2000), creativity and multiple intelligences (Gardner, 1983) as well as creativity and artificial intelligence (Boden, 1990). These three strands of cognitive conceptions of creativity are surveyed and assessed with the purpose of finding out the extent to which each one of them can be fostered successfully within formal learning through creating optimal pedagogical conditions that can enhance each one of them or whether it is an impossible mission.

Studies on the link between creativity and intelligence within engineering education have been spearheaded by David and Arthur Cropley. Their work on creativity has focused on the relationship between high IQ and creative ability. The work of the Cropleys can be traced to earlier works of scholars such as Facaorau (1985). The Facaorau (1985) study was conducted among practising engineers and revealed that practising engineers who displayed high levels of intelligence as measured through intelligence tests combined with generation of unusual ideas and preparedness to conceptually shift their thinking which are the key aspects of creativity are highly rated by their colleagues.

It is important to note that intelligence tests measure intellectual power (high levels of factual knowledge and logical thinking) and intellectual speed (quick recall of facts) which means that scholars who link high intelligence (giftedness) and creativity deal with two forms of thinking that can be diametrically opposed as the former inclines towards conventional thinking and the latter on divergent thinking.

In fact, traditional definitions of giftedness focus strictly on the specified type of performance, that is, on intelligence tests scores and the expected level of performance that an individual should attain to qualify as gifted (Renzulli, 1978) and thus, in such a situation, the link between giftedness and creativity is not straightforward.

Possibly aware of this challenge that links creativity with high intelligence and in a crucial departure from traditional meanings of giftedness, Cropley (1995) argues that true giftedness includes creativity. Cropley's position on giftedness was not new as such liberal definitions of giftedness had already been fiercely debated in psychology and educational settings especially in the USA where intelligence and other psychometric tests remain popular. For instance; in the late 1970s in the USA, the United States Office of Education (USOE) had come up with a definition of giftedness that included creativity and productive thinking in addition to high intelligence and that proved quite popular in education (Karnes and Collins, 1978). The more liberal meaning of giftedness, which includes creativity, transcends human abilities that are reflected in intelligence, achievement, and aptitude testing and compels a lesser accentuation on the precise estimates of individual performance and potential and thus it opened up new challenges for the traditional exponents of intelligence testing – how far they were prepared to go on the objective/subjective continuum to allow for a broader spectrum of human abilities (Renzulli, 1978). Studies that link intelligence and creativity thus played a major role in expanding the meaning of giftedness but posed new challenges. First, creativity brings subjectivity into its measurement and thus places greater emphasis on the opinions of “*qualified human judges*” (Renzulli, 1978: 181). Baillie and Walker (1998: 36) similarly suggest that “*creativity is a convenient label for what is a quintessentially subjective phenomenon*” with implications for its systematic fostering in education.

Second, creativity opens itself up for multiple interpretations so that it can easily be reduced to conceptually ridiculous levels. Third, the link between creativity and high performance compels a rethink on the cut-off percentile as research shows that the vast numbers and proportions of people that are considered productive or creative are not necessarily those people that score at the ninety-fifth or above percentile on standardized tests nor are they, axiomatically, straight-A students. According to Renzulli (1978), most of the creative/productive people are those who are more likely to score below than above the ninety-fifth percentile. In other words, the link between intelligence and creativity is inherently problematic especially when one considers that they represent distinct forms of thinking.

In Japan, academically weaker students are encouraged to take skill-oriented courses that use various creativity strategies to develop their creativity including computer problem-solving exercises (Forrester and Hui, 2007). This may be motivated by the fact that creative people are not necessarily those that score high in intelligence tests. Studies on intelligence and creativity have found that creative accomplishments are not necessarily the function of measured intelligence. Wallach (1976: 57), drawing from a review of many research studies dealing with academic aptitude tests and professional achievement, inferred that:

“Above intermediate score levels, academic skills assessment are found to show so little criterion validity as to be a questionable basis on which to make consequential decisions about students’ futures. What the academic tests do predict are the results a person will obtain on other tests of the same kind”

Based on Wallach’s conclusion, it is not unreasonable to suggest that academic achievement in formal learning has very little connection with more socially pertinent kinds of achievement so that high academic performance cannot always be directly linked with real life accomplishments.

This general delink between intelligence test scores and academic performance on one hand and creativity and real life accomplishments on the other hand plus the relatedness of high adulthood achievements and high non-academic accomplishments such as in extracurricular activities suggest that the connection made between intelligence and creativity is not a very strong one. A study conducted by the American College Testing Program called 'Varieties of Accomplishment after College' found that *the adulthood accomplishments were found to be uncorrelated with academic talent, including test scores, high school grades and college grades* (Hoyt, 1965: 55). Hoyt (1965) reviewed reports on the relationship between traditional indicators of academic success and post-college performance in areas of engineering and medicine and is the most authoritative. Hoyt (1965) concludes that traditional academic success indicators have an extremely modest correlation with various indicators of success in the adult world.

Academic achievement as measured in terms of knowledge mastery can be declared to be relatively independent from educational growth and development. The implications of the non-correlation of measured intelligence and creativity are huge in engineering education and were correctly picked up in studies conducted by Snyder (1967) and Gluskinos (1971). Snyder (1967) conducted a study among engineering students at a USA university which shows that engineering students who attempted novel solutions to problems dropped out of engineering courses three times more often than those students that operated within the framework of conventional solutions. Another study conducted by Gluskinos (1971) among engineering students could not find any correlation between creativity as measured through a creativity test and the cumulative Grade Point Average (GPAs) in engineering courses. It is important to know that even within engineering, the correlation between measured intelligence and creativity could not be convincingly established as adduced from current literature. In recent times within engineering, the relationship between giftedness and creativity was revisited by Sternberg and Lubart (1992) and Cropley (1995) who both argued that creativity adds an important dimension to intelligence so that true giftedness subsumes creativity.

The position of these authors on giftedness is not new but reiterates the Three-Ring Conception of giftedness which claims that creative people that have achieved unique accomplishments and creative contributions consistently illuminate:

“A relatively well-defined set of three interlocking clusters of traits. These clusters consist of above-average though not necessarily superior general ability, task commitment and creativity” (Renzulli, 1978: 182)

According to the Three-Ring Conception of giftedness, no single cluster defines giftedness; rather the interaction among these three clusters constitutes giftedness and thus all three clusters contribute equally to giftedness.

Taking this cue, Cropley and Cropley (2000) conducted a study among 64 male engineering undergraduates who received three lectures on creativity just at the onset of an engineering course on innovation. These undergraduates completed a creativity test and 37 of them also received individual counseling based on the creativity test scores.

The remaining 27 undergraduates took the creativity tests with the 37 students but did not receive counseling and thus forming a control group with respect to counseling. A retest was conducted six weeks later and Cropley and Cropley (2000) found that the counseled students were more innovative as compared to the control group who only demonstrated less inhibition in dealing with ideas. This study also found that machines developed by the counseled students were more creative than those of the 27 students in the control group. Cropley and Cropley (2000) concluded that explicit training and counseling on creativity was associated with changes in behaviour not only as determined through tests but also on practical activities.

The Cropleys study is significant in that it first, restored the importance of explicit training on creativity within formal engineering learning and thus put to rest notions around whether creativity can be taught through conditions of learning.

Second, it shifted focus away from the entrenched link between creativity and individual talent and, brought to the surface the reality that individual creativity, even when conceptualized within the giftedness discourses, can still be enhanced through conditions of formal learning.

Third, it confirmed the views of Sternberg and Lubart (1992), Cropley (1995) and the Three-Ring Conception of giftedness that true giftedness includes creativity. Fourth, it demonstrated that students with high IQs who obtain good grades in formal learning tend to be outstripped by students with both high IQs and high creativity when judged in terms of their innovative products. It is, however, important to note that this study was not the first study conducted on the relevance of learning context (training on creativity) in enhancing individual creativity. Gawain (1974) unimpressed by the general tendency in engineering education to emphasize mathematics and engineering processes and analysis at the expense of devoting time and effort on developing students skills and confidence in engineering synthesis and creative design, argued for the restoration of a more equitable balance between teaching engineering concepts and processes and, training students on synthesis and creativity. A conceptual paper by Gawain (1974) touched on critical aspects of changing faculty culture through incentivizing efforts of lecturers that demonstrate balancing teaching of engineering concepts and processes with training students on engineering synthesis and creativity.

Representing an important departure from traditional meanings of intelligence, another body of studies on intelligence considered the concept 'intelligence' to be too narrow and suggested multiple intelligences – linguistic, logical-mathematical, spatial, body-kinesthetic, musical, naturalistic, interpersonal and intrapersonal – as a way forward on the relationship between intelligence and creativity (Gardner, 1983). In relation to creativity, Gardner's argument is that creativity can be achieved in each of these multidimensional categories in varying degrees depending on the specific talent an individual has.

According to Gardner (1983), a person can be excellent in one form of intelligence and lack in another because the human intellect consists of a set of semi-autonomous computational devices which are each quite capable of processing certain kinds of information in certain kinds of way. Each of the eight major intelligences thus contains sub-intelligences which function to influence how major intelligences deal with information. Gardner's view of creativity within multiple intelligences suggests that individual creativity is possible in one or more of these intelligences so that most people can actually become creative.

Howard Gardner, in his book, *Frames of Mind: The Theory of Multiple Intelligences*, published in 1983 argues that IQs do not capture the full range of human intelligences and he is unambiguous in condemning the assumptions that are made in IQ measurements. However, Gardner (1983) has also received a share of criticism but before we deal with that criticism, it is important to note what Gardner puts on the table of creativity. In the first instance, the meaning of creativity is broadened from the narrowness of giftedness to accommodate more people than the creative genius brigade counseled. In the second instance, intelligence is clearly defined as the capacity to solve problems or to fashion products in one or more cultural settings thus locating creativity firmly within the inventive and innovation discourses. In the third instance, Gardner's view of intelligence locates creativity within cross-cultural perspectives of human cognition so that creativity is seen as a human activity that is conducted within socio-cultural settings which brings both opportunity and constraints on what creativity can reasonably achieve. Gardner's Multiple Intelligences theory (MIT), however, is criticized for not expanding the meaning of creativity rather it is seen as providing alternative names to ability or personality.

My concerns with MI theory relate to the fact that as all other theories that link creativity with intelligence, within the mould of psychological measurements and scientific framing of creativity, MI theory continues to locate creativity within the 'talent and inclination' discourses.

However, MI theory's recognition of the socio-cultural nature of intelligence and, by correlation, of creativity does take the debate on creativity forward. Within engineering education, MIT is relevant to the extent that it encourages the development of personal creativity in any of the domains mentioned in Gardner's book. Creativity development within MIT depends on, first, identifying the strength of an individual in any of the domains of multiple intelligences through psychological testing, and then second, efforts to enhance creative expression can be attempted within the framework of personal creativity (Gardner, 1983). It is, however, relevant to mention that Howard Gardner still operates within the framework of linking high ability with creativity except that this occurs within a broader domain and creativity remains largely locked within an innate individual talent discourse.

Another body of research on creativity and intelligence locates itself within the area of linking creativity with artificial intelligence and asks questions around whether mechanical creativity is possible, and if the answer is yes, whether it can lead to mechanistic theories of creativity and whether these mechanistic theories of creativity can direct efforts on learning and enhancing creativity in formal engineering learning. An important work on these questions around AI is that of Margaret Boden in her book, *The Creative Mind: Myths and Mechanisms* (1990) which provides a philosophical take on creativity and machine-based creative problem-solving. In this book, Boden argues that creative thought results from the application of existing knowledge and that mechanical creativity, while it is work-in-progress, is possible. Boden further describes creativity as consisting of two distinct sets and types. In her analysis of creativity, creativity can first, deal with a situation where a creative person develops a concept which, from the point of view and best knowledge of this person, has never been created before.

Boden calls this set of creativity the P-creativity (psychological creativity) which squares up, to a larger degree, with Weisberg (1993) notions of creativity that suggest that creativity can be understood in terms of familiar psychological processes which involve creative acts that proceed incrementally in small steps and draw from past experiences and efforts by means of exerting conscious mental processes.

Second, creativity can involve a situation where a creative person can come up with a completely new concept that pioneers new ways of seeing, thinking and doing. She refers to this set of creativity as the H-creativity (Historical creativity) because it involves newness in relation to the whole of human history. Boden also provides two types of creativity in terms of whether the new concepts require identification and location within a particular conceptual domain or change the rules that have been informing the conceptual domain. The former type of creativity is exploratory while the latter is transformational. There are important considerations in Boden's conceptions of creativity which require engagement prior to finding out whether such conceptions of creativity can be learned and enhanced within engineering education.

Creativity, in Boden's conceptions, can be deliberately and consciously initiated by individuals for purposes of exploration or transformation and both types of creativity call for different questions and seek different anomalies within the conceptual space. Furthermore; Boden's take on creativity is very much cognitivist in that it makes use of psychological tools of algorithms and heuristics packaged in the form of computational models of cognition to advance individual creativity. However, Boden offers no further details on the notion of a conceptual space or domain in which exploratory or transformational creativity can take place. This task is left to one of the proponents of Boden's notions of creativity – Geraint Wiggins (2001). Wiggins (2001) attempts to define Boden's conceptual space in far broader terms than those which Boden offers by defining such a space as a set of definitional rules that people in that space use to make sense of what they do.

Wiggins (2001: 2) suggests that Boden, by providing a generally loose definition of the conceptual space in terms of definitional rules which are not clearly stated and are possibly generative, has blurred the *"distinction between the rules which determine membership of the space...and other rules which might allow the construction and/or detection of a concept represented by a point in the space"*.

Without belabouring the point that Wiggins makes in elaborating on the concept of conceptual space within AI as postulated by Boden, it is relevant to briefly focus on how Wiggins's definition of the conceptual space guide the AI creative process. Wiggins defines the conceptual space in which exploratory or transformational creativity can take place through characterizing it in very abstract terms which makes traversing such a space not easily accessible even by his own admission (Wiggins, 2001: 5). Wiggins (2001) derives a mathematical formula in which key variables related to the conceptual space are given symbols that either represents constraining forces or forces that allow for movement within the space which are all geared on developing a distinct language that can guide the creative process. Such an approach to creativity enablement obfuscates by use of obscure models and language rather than provides accessible tools for learning and enhancing creativity within the framework of AI.

Creativity is a complex phenomenon on its own and having to use complex tools to navigate creativity is placing too much burden on the person who attempts to support understanding of human creativity. It is in this sense that AI, while it provides hopeful prospects of enhancing creativity, may not immediately be relevant to engineering education in its present form. It may well be that some engineering educators have begun using it but it remains mostly inaccessible because of its scant theoretical infrastructure especially as it relates to engineering education. Stephen Smoliar, a senior research scientist at the Institute of Systems Science in Singapore, has been involved in investigating the relationship between computer-based multimedia systems and creativity enhancement since the 1990s thus provides hope that AI may develop into an area of creativity that involves features of not only learning but enhancing human creativity through mechanistic theories (Smoliar and Mynsky, 2003).

Schank and Foster (1995) argue that if progress has to be made in modeling human capabilities such as creativity through AI then focus should go to developing AI research strategies and not philosophical discussions and thus confirming that more work needs to be done in AI before it becomes a force to reckon with in enhancing creativity within formal engineering learning.

They further concur with Boden that it would make more sense to pay particular attention on P-creativity which they define as creative explanations of “*ill-understood or anomalous phenomena in one’s world*” (Schank and Foster, 1995: 131). This position on creativity resonates with Arthur Cropley’s meaning of ordinary creativity which represents an important shift from his initial stance that creativity is solely the exclusive preserve of those endowed with ‘talent and inclination’ (Cropley, 2001: 12). In a clear criticism of Boden’s contradictory stance on the P-creativity which she reveals by defending the need for P-creativity in AI but using examples from art and science which reflects what Schank and Foster (1995: 132) call “*rational reconstructions of scientific breakthroughs*” which slants more toward the H-creativity. Schank and Foster (1995) suggest that our understanding of creativity is more likely to come from the modeling of everyday P-creativity ideas and insights.

In other words, AI efforts on creativity should, according to Schank and Foster (1995), focus on assisting people to generate explanations in situations where retrieved explanation patterns do not provide satisfactory or adequate explanations about a new event. The development of mechanistic theories should, this can be inferred from above, focus more on modeling this kind of creativity. Schank and Foster (1995) provide a framework of facilitating such a creativity process by identifying two separable processes within the creative application of explanation patterns. The first process relates to searching for new candidate explanation patterns for consideration. The second process which they term ‘tweaking’ entails changing the constraints of a given explanation pattern such that it applies adequately to the current event so that heuristic strategies for ‘tweaking’ can involve, inter alia, the relaxation of the set membership constraints, re-hypothesizing about an agent when the initial agent cannot be pinned down to an action.

According to Schank and Foster (2001: 132), the 'tweaking' model has already been used in a programme called SWALE that operates on the basic algorithm that consists of five stages: *"anomaly detection, memory search for an explanation pattern, attempt to apply explanation pattern, tweaking of explanation pattern and, integration into memory with appropriate generalizations"*. In this sense, tweaks are designed in such a manner as to operate on explanations within multiple domains. What makes programmes based on tweaking to have potential to enhance creativity is that such programmes attempt to generate new knowledge through disturbing existing knowledge representations. However, and receiving little attention in the nexus between AI and creativity, are issues first, around user-friendliness of these AI initiatives that are obviously designed to facilitate human creativity although not exclusively as the future focus of AI may involve operation systems that can solve unanticipated glitches in their own system; second, issues around the feature of creativity that it can be learned and enhanced, which ties creativity enhancement with problems of learning that need further analysis in AI.

Schank and Foster (1995) consider the strong nexus between creativity and problems of learning as the greatest challenge facing AI research thus problematizing the relationship of AI as an enablement and enhancer of creativity within engineering education. As already stated AI remains largely inaccessible in the broader scope of engineering education but offers positive prospects if it can successfully deal with that strong nexus, that is, how creativity can be learned and enhanced through AI mechanisms.

In conclusion, cognitive conceptions of creativity provide engineering education with very little space to enhance and encourage the growth of creative problem-solving and thus remains largely inaccessible to engineering students. In the words of Baillie and Walker (1998: 36) relating to the link between creativity and intelligence and its possible fostering within engineering education *"There appears to be a great deal of similarity between the way we collectively regard creativity and other characteristics of performance, such as intelligence, or aptitude or ability...but one can go no further. There is no access to creativity, no opportunity to cultivate it as a skill..."*

Socio-Cognitive Conceptions of Creativity and Engineering Creativity

Development

Engineering creativity is, in its fundamental essence, based on creating or improving on products or services that lead to various human conveniences (Pitso, 2008). It is thus oriented towards design and technical processes that can produce novel outputs and outcomes with certain impacts on society. However, the design and technical processes involved in such creations or improvements are too complex and require technical knowledge and expertise of engineers drawn from different areas of specialization thus compel collaborative work which involves the formation of teams.

Historically; engineering, like the science it subsists on, has tended to differentiate to a point where very cognate engineering disciplines even talked past one another (Murphy, 1990). Complex design challenges have, however, reclaimed the space and spirit of cooperation and sharing among engineering disciplines that resulted in de-differentiation leading to studies around the nature and effects of teams, the meaning of shared knowledge across disciplines, aligned intent, conversations and, issues around the degree and quality of participation as related to engineering outputs and outcomes. Questions relate to the effectiveness of these issues in resolving the design problems at hand. A body of literature exists that study these factors in relation to whether they are desirable aspects of design and problem-solving and this literature is drawn largely from social and organizational psychology. Engineering education scholars that systematically investigate issues around how the resolution of complex design problems work and how they can be enhanced to achieve better results have tended to focus on three interrelated factors involved in the resolution of complex design problems. These factors are the technical knowledge of the people involved in resolving the design problem set to be drawn largely from their cognitive faculties, boundary transgressions necessary for resolving design problems (interdisciplinarity) and shared knowledge which is required for resolving the design problem at hand (Avnet, 2009).

The emphasis on cognitive factors (specialized engineering knowledge) and the relevance of closer cooperation among engineering actors to resolve the design problems at hand (the social aspects) have compelled the framing of such creative work within the socio-cognitive perspective. The socio-cognitive perspective conceptualizes creativity as an area of highly trained individuals operating within contexts to resolve non-routine design problems. This perspective attempts to combine the liberal conception of giftedness which considers giftedness as constituted by above-average intellectual capacity, task commitment and creativity, and social aspects that facilitate closer cooperation such as teamwork.

Teamwork, within the engineering socio-cognitive perspective, refers largely to the team of engineering experts that collaborate on the design of a complex system such as spacecraft (Avnet, 2009; Vallas, 2005). The socio-cognitive frame thus focuses on expertise and team functional diversity (Salas, Rosen, Burke, Goodwin and Fiore, 2006). However, aspects of group dynamics such as competition, norming (aligned intent, safe conversations, distributed tentativeness and externalization) as well as degree and quality of participation in the team come into play. Expert teams have been extensively covered in literature (Avnet, 2009; Salas *et al.*, 2004, 2006). According to Avnet (2009: 49), a team of experts works more effectively within the framework of a theory on performing teams. Similar to Avnet (2009) on expert teams, Salas, Kosarzycki, Tannenbaum and Carnegie (2006: 440) suggest that a team consisting of experts is more than just a group of experts coming together but involves:

“A set of interdependent team members, each of whom possesses unique and expert-level knowledge, skills, and expertise related to task performance and who adapt, coordinate and cooperate as a team, thereby producing sustainable and repeatable team functioning at superior or at least near-optimal levels of performance”

Given this understanding about expert teams; Salas *et al.*, 2006 reviewed literature in this area and came up with a set of characteristics that can be associated with expert teams. Expert teams are characterized by the use of shared mental models, learning and adapting in line with the dictates of the design problem at hand, self-correcting mechanism, clear but flexible role definition, shared purpose and highly skilled leadership, strong trust and confidence on the ability of the team to overcome design challenges and succeed and the self-belief that the design tasks can be performed successfully (Salas *et al.*, 2006). While this study is not necessarily about expert teams, information on expert teams provided an important framework for analyzing student' teams in respect of their performance in the *learnshops*. While other aspects of expert teams may not be directly relevant to the study, they offer important insights on the framing of the student' teams in this study.

For instance, the X-teams theory developed by Ancona, Bresman and Kaeufer (2002), posit that five features define expert teams which are external activity, expendable tiers, extensive tiers, mechanisms for execution and flexible membership. The authors, after extensive testing of the theory, came to the realization that X-teams have tended to demonstrate increased and higher performance than static, traditional teams which are often focused internally. Pertinent to this study with regard to the X-team theory is the fact that the theory has proved to work well in situations where a flat organizational structure is in place, the nature of the problem is as complex as to warrant sharing of sophisticated and dynamic information as well as a direct interdependence of the team's work and activities that happen outside the sphere of the team. Avnet (2009) investigated the effectiveness of this theory within a diverse technical team which sought to build a spacecraft and found the theory to stand most of the time. However, more relevant to this study and setting up the stage for the X-team model is the study conducted by Gruenfeld, Martorana and Fan (2000) which investigated the concept of 'worldliness' on the performance of a team. The concept included three very similar aspects of the X-team model – external tiers, flexible membership of the team and external activity. External tiers refers to the team's external interactions vital for developing links with the forces outside the team in order to deepen the team's ideas.

These three aspects of the model deal with exchanges that take place among the team members as they shift positions from one team to another, which Gruenfeld *et al.* (2000) call 'itinerant' membership. According to this study by Gruenfeld *et al.* (2000), 'itinerant' members, that is, those members who shifted positions from one team to another even temporarily and then returned to their original teams, were not likely to be immediately relevant to the teams efforts on generating useful ideas that can lead to solutions but tended to exert influence on indigenous members in terms of generating novel ideas. This study shows the benefits of well managed switching of one or two members from one team to another and deals specifically with the negative effects of rigid team membership which can lead to groupthink and tunnel vision (Avnet, 2009; Cannon-Bowers, Salas and Converse, 1993). Itinerant membership also deals effectively with positional modeling which refers to gaining information and opportunity to observe and learn about the other team members' roles and how that shapes the sharing of knowledge.

Shared knowledge within the context of heterogeneous expert teams can pose a serious challenge to the effectiveness of teams because members bring highly specialized, technical knowledge into the team which brings the concept of 'professional diversity' coined by Ancona and Caldwell (1992) into play. According to these authors, professional diversity in expert teams can be both an advantage and a curse as it can lead to *"more creativity to problem-solving and product development, but it impedes implementation because there is less capability for teamwork than there is for homogenous teams"* (Ancona and Caldwell, 1992: 321). Another challenge posed by such teams is what I call *"distributed tentativeness"* (Pitso, 2009) which refers to the willingness of team members to learn from one another within the framework of corroborating claims made. Distributed tentativeness entails a situation where team members learn to defer to suggested options on the basis of the promise each option brings into the problem-solving situation.

However, over time team members may begin to defer to options not because of their promise to lead to another stage in the problem-solving situation but because a member or some members have over time built a reputation in terms of the consistency of correctness of their previous ideas which increases trust and future acceptance of the options advanced by the trusted member. According to Bonner, Baumann and Dalal (2002) who have studied the effects of member expertise on the decision-making processes and performance of teams, small teams (three-member teams) are actually more susceptible to relying on the ideas of the highest performing team member and tend to readily defer to the 'expert' member's options or ideas. Similarly, but focusing on generally marginalized members in the team, the view of Jackson (1996), based on a survey of literature on teams is that marginalized members' ideas or options tend to be ignored, advertently or inadvertently, mainly because the marginalized members lack the confidence to express a differing idea or option, especially if it goes against the position of the most trusted member of the team. Teams that proceed on the basis of the dominance of one or two members tend to fall into the trap of leadership cult.

The leadership cult tends to exhibit consistency of deferring to the views of the dominant member or members without so much as to demand corroboration which, in the medium to long term, may compromise collaboration and lead to less team creativity as well as increased groupthink and tunnel vision hence the need for itinerant membership (Jackson, 1996, Cannon-Bowers *et al.*, 1993). According to Cannon-Bowers *et al.* (1993), shared knowledge can become a serious problem in cases where team cohesiveness is based on leadership cult which may compromise realistic appraisal and fairer consideration of all options that team members bring into the team's equation. Avnet (2009) investigated the relationship between shared knowledge and the engineering design process through the review of existing studies on shared knowledge and cognition (formation of mental models) in order to examine the phenomenon of shared mental models.

In my view shared mental models within engineering design process represents a significant contribution in the debate on whether a socio-cognitive perspective on solving complex, non-routine design problems can be treated as a different theoretical framework from the traditional cognitive or recent social conceptions of creativity within engineering and engineering education. In the context of shared knowledge, the concept of 'shared' reveals the social aspects of the socio-cognitive exercise and the huge challenges it poses on creative problem-solving, especially in areas of engineering design while 'knowledge' refers to the technical know-how that each engineering actor possesses from their own discipline. My basic argument is twofold. First, the sharing of mental models within the context of resolving a complex problem such as a design and building of a spacecraft can be extremely low because the overriding principle is that of usefulness and resolving each aspect and step towards the design and building of the product. Tenure diversity, which refers to the extent to which each expert joined the team at different times (Ancona and Caldwell, 1992), can account for low shared mental models especially among very heterogeneous teams because stages in the design process may compel experts from similar technical background and expertise to join up to solve a step in the design process which may increase the possibility of shared mental models among relatively homogenous teams.

In other words, shared mental models may be more plausible when teams are generally homogenous than when they are heterogeneous in situations where teams are assembled to resolve a specific design problem which is more important than the sharing of mental models.

Based on this understanding, it is not unreasonable to suggest that what is termed a 'socio-cognitive' perspective may well be a sociological stance as social conceptions of creativity often suggest that the collective effort in resolving a problem at hand is better enhanced than when only an individual is involved. I engage the issue of shared mental models within engineering teams further to make my argument clearer.

Mental models are weakly defined as “*the way an individual perceives his or her environment* (Avnet, 2009: 52) which may lead to organized knowledge that assist an individual to make sense of it, draw conclusions and gain experience of events by proxy (Klimoski and Mohammed, 1994). Klimoski and Mohammed believe that mental models are more than metaphorical representation of reality (abstraction) but can lead to identification of measurable variables. Rouse, Cannon-Bowers and Salas (1992) argue that mental models not only play the role of attaching labels to knowledge in order to make sense of it but tend to add value in human understanding of its surrounding. Rouse and Morris (1986: 351) take the stronger position that mental models are:

“Mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states”

Another point worth mentioning and well articulated by Avnet (2009) is that mental models come in different types as shaped by the underlying content which is a crucial element on investigating the possibility of shared mental models. According to Cannon-Bowers, Salas and Converse (1993), two mental models can be discerned in literature which are task-oriented mental models that facilitate the achievement of a specific task and eventually of the expected output or outcome and team-oriented mental models that allow individuals to function effectively as members of a particular team.

Empirical studies have been conducted in order to distinguish between task and team mental models. The study conducted by Mathieu, Heffner, Goodwin, Salas and Cannon-Bowers (2000) on the distinction between these two constructs found that in cases where team mental models demonstrated high levels of sharing, such efforts were positively related to team performance and that such relationships were fully mediated through team processes. It is, however, important to note that these authors used dyads to investigate the correlation between team mental models and team performance. The team sampling also shows a relatively homogenous team which, by definition, already have relatively common mental models.

The question is what would happen if a larger, heterogeneous team was involved in the study. In the same study of Mathieu *et al.* (2000), the authors found that in cases where the task mental models are shared there existed a weak correlation between shared task mental models and performance. This is not a surprise given that in situations where tasks completion is rated high, the likelihood to worry about sharing will always be very low.

However, it is also important to note that in studies conducted in larger sample size (Mathieu, Heffner, Goodwin, Cannon-Bowers and Salas; 2005), the shared mental models tended to be strongly correlated with team processes. This is a very important finding because it suggests that the lesser the team size, the more likely that team members may remain entrenched in their own mental models and the bigger the team size, the more likely that the team processes would take centre stage and thus the more likely that team members can demonstrate reasonably high levels of cooperation. This view is similar to the findings of Bonner *et al.*, 2002, referred to earlier, that show that smaller teams tend to rely on the ideas of the highest performing members of the team. Further studies on larger teams were needed to corroborate the effects of shared mental models within a larger team on team performance. The first difficulty that was faced by those who sought to build on the shared mental models that involved two or three members in cases of larger teams was the retention of the simple mean-based aggregation of the dyads or triads of shared mental models in the team. The mean-based aggregation would be impossible to transfer to the analysis of the broader effects throughout the team.

Langan-Fox, Anglim and Wilson (2004: 426) article demonstrates the immense challenges embedded in extending the shared mental model based on two or three team members to the larger team mental model which they define as “*a synergistic functional aggregation of the [team’s] mental functioning representing similarity, overlap, and complimentarity*”.

Avnet (2009) indicates that an alternative view of team mental models based on the broader dynamics of the entire team has become inevitable and would have to eschew the construction of a metric of sharedness. Indeed, some studies have preliminarily begun to tease the notion of how to document the thinking of a larger team in respect of decision-making and point to the use of qualitative and anecdotal methods.

Klein (1998), focusing on observation of large team cognition as it relates to decision-making, presents a study that was conducted among highly experienced professionals who had to deal with ill-defined goals, inadequate information and high time pressures, and which focused on how these factors bear on their decision-making. After observing several professionals in terms of meeting the criteria of ill-defined goals, insufficient knowledge and time pressures, Klein came up with a Recognition-Primed Decision (RPD) model which deals with the idea of mental simulation. Mental simulation, similar to a mental model, entails a situation where a decision-maker employs his\her cognitive faculty to construct a model which he\she sets in motion to observe its effects. The advantage of RPD is that it allows for corrective behaviour prior to the actual making of a specific decision. The RPD model had to apply in naturalistic settings that involve large teams to be of some significance. In dealing with this aspect of the study, Klein (1998) developed the idea of 'team mind' analogously to illustrate how large teams grow and act. Klein's basic premise is that teams function in similar ways to individual mind with some basic functions such as memory, span of attention, perceptual filters and learning, as well as developing capabilities such as competences, cognition, metacognition and some form of identity. In addition to these characteristics, teams can develop high-level mental processing during engagement with complex, real world activities which include planning and dealing effectively with uncertainty which are more directly linked with collaborative ambiances (Klein, 1998). However, research on these issues remains scant so that Klein and other scholars investigating the role of macro-cognitive processes in teams that collaborate in naturalistic environments relied on anecdotal evidence and informed conjecture to set up these initial ideas in this area of teamwork.

I spent a considerable time attempting to make sense of the relationship between creativity as conceptualized socio-cognitively which foregrounds notions of expert teams and team performance. In essence, the relevance of studies on expert teams in this study relates to how these issues around expert teams map themselves out in teams of engineering students who are engaged in similar creative problem-solving processes although of far less sophistication and complexity than in expert teams who are building a spacecraft. Key issues that are taken forward into this study include the very underpinning of expert teams within the socio-cognitive framework. I believe that this framework remains under-developed and lacking in theoretical precision especially when employed within the engineering field.

First, there is a glaring gap of analysis in literature on socio-cognitive conceptions of expert creativity within the context of teams. Most of the literature surveyed with regard to engineering expert teams emerges from social and organizational psychology which is then used to make sense of engineering expert teams. Few studies exist that examine critically what engineering teamwork means as understood within the engineering processes of resolving complex, real world problems and how that can, in turn, form the basis for developing an appropriate theoretical framework for individual creativity in context.

Second, studies in engineering that involve uncertainty (ill-defined problems) underpinned by a socio-cognitive perspective have almost always turned on the premise that the technical knowledge of the engineers (the cognitive aspect) should be separated from the role of human engineers operating in naturalistic settings to resolve complex problems. This epistemological binary is, I argue, the one that results in the coining of the concept 'socio-cognitive' perspective. In other words, the link between the technical knowledge of engineers and the human factors involved in engineering processes that attempt to resolve problems in real settings such as teamwork and interpersonal skills which are concepts associated with psychology and sociology are kept separate.

I believe more as to avoid ontological, epistemological and methodological confusion so much that it warranted the creation of separate engineering fields such as cognitive systems engineering or cognitive ergonomics. This branch of engineering known as cognitive systems engineering or cognitive ergonomics deals with the relationship between human engineers and machines engaged in designing systems for human use (Hollnagel and Woods, 2006). The framing of this branch of engineering is socio-cognitive and has developed a methodology for the design of human-centred technologies. This general methodology for designing human-centred technologies is called socio-cognitive engineering which integrates software, task, knowledge and organizational engineering to develop computer systems that support training and professional work (Sharples, 2000).

The relevance of this socio-cognitive engineering methodology is the extent to which the methodology can be used to analyze the complex interactions between people and computer-based technology in ways that transform the analysis into useful, elegant and utilizable socio-technical systems which deals with technology in context. This methodology has been developed over more than a quarter of century through a series of multiple projects ranging from tele-writing system (McConnell and Sharples, 1983) on to technologies that support radiology training and decision systems (Sharples, 2000).

While the case studies that I used in this study deal with existing technologies or systems in respect of sustainability of resources such as water, paper and energy within the context of the students' institutions, I use very similar instruments of analysis gleaned from the literature surveyed in this section except that I consider the framing of the reviewed studies within the socio-cognitive perspective as too similar to social conceptions of creativity to warrant a separate theoretical framework.

Key aspects that are taken further from this literature includes the relationship between shared mental models and the team's effectiveness and how shared mental models among engineering students affect team's effectiveness organized within the framework of an invitational pedagogy.

The areas that received scant attention on expert teams that attempt to resolve complex design problems include whether forms of participation have any effect on the quality of decision-making. This matter is receiving similar attention within the field of organizational psychology and management as teamwork. The core debates relate to whether stakeholder participation in the form of expert engineers or engineering students can assume different forms so that each of the forms of participation can be associated with marked different outcomes (Cotton, Vollrath, Lengnick-Hall and Froggatt, 1990). This study is concerned about the level of participation of engineering students in a learning context in respect of resolving complex design problems, mainly at a level of improvement, and thus differ significantly from tasks and teams associated with designing big engineering products. However, the core challenges of teamwork, shared mental models, iterant membership, norming and the use of technology to support human efforts fall within the framework of this study.

Engineering education studies that focus on teamwork, interpersonal skills, communication and participation are numerous and are reviewed further here. The teamwork literature has been extensively covered in this section at a materially different level than the level it takes within engineering education. Engineering students cannot claim to be experts, thus the high technical acumen that, at least, warrants the epistemological binary between the technical and socio-psychological in the case of expert teams cannot be considered as present in the systematic investigation of how engineering students develop their creativity. It is important to indicate that interest in creativity within the engineering education was brought about by huge dissatisfaction from industry globally about the kinds of graduates industry was receiving.

However, engineering education studies tended to focus on designing educational and training programmes that attempt to encourage the growth and development of creativity mostly as add-ons rather than as efforts to transform curricular and pedagogic practices. Furthermore, there appears to be confusion on the theoretical underpinning of these studies and most of them eschew explicit discussion on theoretical framing.

Studies on fostering creativity in engineering education can be placed in three categories. Those that attempt to develop a conceptual and theoretical framework for fostering creativity, those that develop educational and training programmes to encourage creativity and test the effectiveness of such efforts and those that attempt to initiate curricular and pedagogic reform that can lead to focus on creativity (Törnkvist, 1998; Forrester and Hui, 2007; Cropley and Cropley, 1998; Cropley, 1992; Dillon, 2006; Baillie and Walker, 1998).

Each of these categories of study accentuates one or more of the aspects of social conceptions of creativity such as group discussions, communication, externalization, participation and most of the issues associated with teamwork. Furthermore, these studies compel a shift from basic dualism where things are judged in terms of wrong and right to situations where judgements are not so straight forward. Last, these studies cannot claim that students already possess high-level technical skills that warrant treatment at the same level as in expert teams which may justify the use of an epistemological binary between technical and social factors. These studies rather may be scaffolding such expert teams hence the review of expert teams literature.

Based on this understanding, I have reason to suggest that studies on fostering creativity in engineering education are best located within social conceptions of creativity. Social conceptions of creativity may be considered as generally inimical to creativity assessment yet that is more an unfounded perception than it is a fact as all forms of creative work require some form of validation to be worthy of such effort. Creativity assessment may, however, take many forms including psychological assessments that do not materially compromise the social constructions of creativity (Pitso, 2009).

Social Conceptions of Creativity and their Implications for Fostering

Engineering Creativity

Taking a sociological and organizational stance, social conceptions of creativity accentuate socially constructed creativity and rejects; in the context of engineering education; notions of a solitary, independent creative person who unilaterally comes up with a new or improved product or service (Törnkvist, 1998, Fischer, 1999). The design and development of a product or service in engineering is seldom the work of a single genius toiling alone.

The emphasis on social creativity in engineering education is on how to conceive of our learning environments in such a manner as to encourage collective generation of ideas that can lead to new or improved insights, or ideas that can resolve complex, real-world problems that occur in naturalistic settings. The spotlight thus falls on classroom activities that can nurture generation of novel insights or ideas that can lead to resolution of real-world problems. The challenge is on how classroom activities can be organized to allow for collective imagination that can break the mould of conventions using technical and social constructs such as knowledge of engineering, creative problem-solving processes as well as teamwork, interpersonal skills, externalization, passionate conversations and active participation. This approach to fostering creativity within engineering education may require new visions that challenge the scope and thrust of entrenched conventional approaches to problem-solving.

Indeed over the last two decades, there has been a global call for creating new visions in engineering education that can develop graduates with high technical acumen, creative problem-solving and interpersonal skills. Interpersonal skills include skills such as the ability to work in a team, communicate well and work in an environment that is defined by a strong brand of motivated staff that operates collectively using creative processes to improve or design new products or services (Ernst and Peden, 1998).

In a conference specifically organized to address the new vision for engineering education entitled '*Realizing the New Paradigm for Engineering Education*' held in the USA in 1998, a global consensus was reached on what engineering education should be as guarded by its stakeholders in respect of curriculum content, innovative approaches to pedagogy and involvement of students in their own learning from undergraduate level onwards. Attention was specifically paid to the urgency for "*the academic community to rethink the substance and presentation of undergraduate engineering education*" (Ernst and Peden, 1998: ii). The form that such an undergraduate engineering education would take, Eifert (1998) insists, would be determined largely by two forms of knowledge and its understanding.

The first knowledge form entails the understanding of changes in the nature of our 21st Century world pertaining to the nature of work in the post-industrial age that requires more than just efficient manufacturing processes, cost control and good technological base to remain competitive but now also requires staff that can operate confidently in a highly fluid environment that demands mastery of creative processes, getting along well with a variety of people, persuading without alienating and communicating effectively (Ernst and Peden, 1998; Eifert, 1998). The second knowledge form refers to the nature of knowledge itself as it informs what goes into curriculum content and how that knowledge can be transferred to the next person (Eifert, 1998). This new engineering education vision has, over the last two decades, prompted several conferences, reviews and studies that focus on systemic engineering education reform.

This new vision of engineering education suggests that creativity occurs in a group context either at a classroom, enterprise or regional levels and is stimulated largely by the need to meet 21st Century workplace expectations, whether at a level of employment or business venture creation. Over the last decade, studies on fostering creativity as part of the engineering education reform began a process of effecting change through development of conceptual or theoretical frameworks, design and implementation of educational or training programmes as well as focusing on how to assess creativity.

Studies on educational programmes were designed either as add-ons to the traditional engineering curriculum or as attempts on rethinking curriculum enactment, but tended to proceed on the basis that alternative pedagogies that put students at the heart of learning are vital.

As the research impetus to reform engineering curriculum and pedagogy to promote creativity gained momentum in the 1990s, questions focused on the learning environment and the learning theories that dominated it. According to Törnkvist (1998), a hybridization of three teaching approaches led to the general marginalization of creativity in engineering education and their correct analysis may lead to the reclaiming of curricular and pedagogic spaces for developing students' creative abilities.

First, the principle of 'general faculty' led to the organization of engineering education in such a manner as to make sure that existing knowledge takes the form of being taught and learned in a context-free way. In other words, such knowledge had to meet the requirement for universality and applicability across contexts. This is one of the core aspects of modern thought which draws directly from the other thesis of modern thought called epistemological foundationalism. Epistemological foundationalism, according to Murphy (1990: 292), refers to the claim that knowledge can only be justified when it is reconstructed on indubitable foundational beliefs. The thesis is based on the idea that social reality imposes itself on individuals' consciousness from without and that objects have an independent existence such that knowledge derived from them can be considered as hard, real and capable of being transmitted in tangible forms in ways that make it acquirable outside the self (Cohen, Manion and Morrison 2000:6). It is these specialized notions of knowledge that create a binary between those who possess it and those who do not possess it and thus create conditions for acquisition metaphors in learning (transmission and apprenticeship models of teaching) which leads to the next principle that Törnkvist (1998) adduces as responsible for traditional engineering curriculum and pedagogy.

The 'drill and practice' principle, drawing directly from the above assumptions on formal knowledge, encourages passive acquisition of knowledge and thus accounts for the entrenchment of mimetic curriculum and pedagogy in engineering education. I shall elucidate on this point later in this chapter.

Third, the principle of 'conceptual understanding' which refers to the use of abstract mental schemas to figure out our experiences is closely related to the principle of 'general faculty' in the sense that universalizing mental schemas are given preference in making sense of experience in lieu of context-based, situated knowledge that cannot be transferred to other contexts (Törnkvist, 1998: 8-9). This principle accounts for the requirement in engineering that students study mathematics and physical science without so much as to link these subjects directly with the core of engineering education which is to develop both high-level analytical and synthetic skills for solving real-world, complex problems (Törnkvist, 1998).

It is important to indicate that these three principles that Törnkvist (1998) argues are at the heart of traditional engineering have been shaped mostly by behaviourist learning theories. According to Törnkvist (1998), efforts on reforming engineering curriculum and pedagogy have to take into account these outdated learning theories and replace them with those learning theories that put students at the centre of learning and encourage deeper engagement with learning content. Such learning theories are likely to release the thought and time spaces of students and thus may allow engineering as a field of practice to reclaim its basic essence of meeting the requirement for usefulness but also the elegance of its artistic flair.

In a similar take on traditional engineering education, Lewis (2004) suggests that traditional engineering curriculum and pedagogy develop in students habits of thinking that suppress their creative urge and ability. Similar to Törnkvist (1998), Lewis (2004) problematizes the teaching of mathematics and science which tends to encourage conventional thinking which makes it difficult for students to access their creativity which is based mostly on divergent thinking.

Lewis (2004) suggests the use of various approaches of creative problem-solving such as techniques of TRIZ (which will be introduced in detail in chapter 4) to assist students to access their creativity. Baillie and Walker (1998) equally focus on efforts to assist students to access their creative ability through problematizing cognitive conceptions of creativity that generally deny the feature of creativity that it can be enhanced by arranging learning environments in a particular way. These authors went further and presented three case studies that attempted to arrange the learning environment in such a manner as to encourage the 'creative flow'.

For instance, a course designed for first years in the Mechanical Engineering studies focused on developing the professional skills of the engineering students such as thinking skills that could enable them to probe and examine problems related to the postindustrial society (Baillie and Walker, 1998: 37). The programme was organized in such a manner as to encourage teamwork, discussions, role play, debates and industrial visits among smaller groups of students.

Relevant to this study is the fact that in addition to the creation of these learning environments, the programme also paid attention to ethical and environmental issues. We are, however, thwarted in our efforts to assess how the creation of such a learning environment contributes to the enhancement of students' creative abilities because such important constructs as teamwork, discussions, industry visits and environmental issues are not further elucidated to offer a reasonable basis upon which possible pitfalls could be identified and corrected. Indeed, this study is very much based on these key constructs and could have benefitted from deeper analysis of the relationship among them and in relation to fostering creativity. The relationship of these three case studies (programmes) and the curriculum and pedagogy they seek to reform is also not made clear.

Mathews and Jahanian (1999) similarly attempted to develop a pedagogical strategy for enhancing students' creative abilities. These authors also presented three projects. The first project was designed so as to let students to develop a machine design (turntable that could rotate a textbook) in a manner that is environmentally safe.

The second project gave students opportunities to design a smart conveyor belt system that recognize the size of different blocks and the last project called for students to design a model of lift truck that could be handled by an unskilled operator. All these projects met the industrial applications requirements and each lasted for a semester. 66 students drawn from three classes of Machine Design were involved in these projects. A control class was used as a reference class but played no part in the projects. Students were organized in a team form and were given specifications for each project.

The specifications were that students had to work with the materials that were available in their laboratory with no option of buying materials that were not available in the laboratory, students were also not allowed to use ready-made commercial parts and the total costs of building the design was not expected to exceed 75 US Dollars and each model was expected to be environmentally safe. These specifications were considered as key enhancers of students' creativity.

Students were given the latitude to form their own teams which did not exceed four members per team. These projects arrangements were seen as alternative pedagogic strategies from the traditional ones as the challenges embedded in the projects were viewed as giving students sufficient opportunities to be creative. However, each month of the projects' lifespan, options on how each phase of the project could be approached were given to students who made choices and took decisions on the more relevant options. Students were also given opportunities to seek assistance from the lecturers. At the end of the projects, students were expected to make an oral presentation. The conclusion that the authors reached, through conducting interviews with students, was that the pedagogic strategy they tested showed gradual improvement in the creative performance of the students.

A significant body of engineering education research has taken up the issue of using case studies or projects as ways of enhancing creativity.

Almost all of them have restructured the learning environment in such a manner as to allow for collaborative work (teamwork, group discussions, distributed tentativeness, peer groups), development of interpersonal skills such as effective communication (shared meanings, aligned intent, safe conversations) and creative problem-solving processes (Chen, Jiang and Hsu, 2005; Baillie and Walker, 1998; Page and Murthy, 1990; Mitchell, 1998). However, most of these studies on fostering creativity in engineering education tend to mention that collaborative, communication or creative problem-solving constructs were used without really identifying and linking the relationships between each of the constructs and its role in enhancing creativity or even whether such a correlation has been established. For example, the link between teamwork and the release of students' time and thought spaces as possible area for creativity enhancement is not clearly articulated in literature; thus we are left with more questions than answers. Furthermore, the challenge of group dynamics is ignored in terms of how inherent competition in group formations is moderated to allow for closer cooperation and sharing of knowledge.

These studies also fail to demonstrate how changes in the learning environment to allow for students' subjectivities affect the nature of knowledge and how that, in the long run, may influence engineering curricular content and pedagogic practices in terms of such a change in epistemic assumptions that drive such knowledge. One area that does not come out clearly in these engineering education studies is the fact that creative work, whether attempted at the level of the individual, the individual in context or the collective, involves gaining novel and new insights or ideas through research. When conducted in a group context, as of the study being presented in this thesis, the learning environment is organized in such a manner as to allow for students collaborative research. Seeking accurate information to resolve every step of the creative problem-solving, assuming that a systematic form of creativity is more likely to be associated with engineering creativity especially in design, is central to efforts on fostering students' creativity. The critical aspect of creativity-based research is that it leads to new discoveries and tends to deal with complex, real-world issues that eschew neat categorization of variables.

For example, such neat categorization of variables almost always occurs in laboratory studies which often allow students to verify what is already known and obvious to seasoned experts in the field. Creativity-based research may even cross disciplinary borders and traditional site boundaries (academia, industry). I was particularly interested to find out how Baillie and Walker (1998) study conceptualized industry visits by students as part of researching to find creative solutions to real-world problems.

Students' learning in a research mode is not new in science and engineering. It involves, however, creating alternative means of doing classroom things in ways that facilitate creativity development through gain in research skills. Over these last two decades, engineering education globally has been attempting to inculcate this new sense of doing classroom things differently to encourage the growth of creativity especially in undergraduate studies. Over this period, studies focused, on conceptualizing theoretical frameworks that could encourage creativity through changing the faculty or organizational culture and finding effective ways of researching creativity within these organizational constraints.

Dillon (2006) in a conceptual paper, focuses on how higher education disciplines can share ideas and knowledge across and between each other in ways that generate new or alternative ideas that can contribute meaningfully toward the evolution of a creative idea. The assumption Dillon (2006) makes is that the development of creativity in higher education requires an integrated approach hence his efforts to provide a framework that makes interdisciplinarity and multi-disciplinarity possible. Dillon further advances integrativism as a creative activity that is likely to lead to novel ideas and argues that integrativism as used in curriculum is likely to encourage the notion of the pedagogy of connection that may stimulate students' creativity (2006: 77). Dillon's locates his paper within the socio-cultural framework to make a case that a learner or group read a new situation that each encounter anew because the socio-cultural features of that situation compel such a reading; thus a learner/group and context interact and transform each other. The new situations with which his paper is concerned arise through integrative work which advances the view that:

“The human mind works in complex and dynamic interaction with the environment, where meaning is fluid rather than fixed, and information is integrated with experience in processes that involve the continual construction, deconstruction and reconstruction of knowledge” (Dillon, 2006: 71)

Based on this understanding, it can reasonably be suggested that knowledge is context-dependent thus can be produced through and expressed within an activity where the context of an activity is defined as the interaction of factors associated with the place where the activity is conceived, planned and realized, how it is experienced or interpreted by the people concerned, and the social and cultural norms governing these transactions (Dillon, 2006; van Oers, 1998). Dillon’s emphasis on activity illuminates activity theory which Kaptelinin and Miettinen (2005) describe as a powerful analytical framework that assists to reveal the fundamental aspects of social practice. Gruber and Wallace (1999), expressing similar views, consider an activity as a creative exercise which is defined by the nature of the enterprise, the individual’s oeuvre and overall purpose (goals).

Of particular relevance to this study is the view that all activities are social because even when individuals are working alone, their work is determined by social and cultural practices (Stevenson, 2004; Kaptelinin and Miettinen, 2005, Dillon, 2006). Dillon’s contribution in attempting to provide a conceptual framework of integrative work as a way of encouraging creativity rests in representing an integrative work in terms of a ‘sense of place’ and how space in a particular context is used to either encourage or discourage creativity.

Ramphela (1993), similar to Dillon’s position on space mediation as a factor in fostering creativity, identifies four types of space and provides a powerful analysis of how space can be used to advance certain ‘settled truths’ about what constitutes knowledge and pedagogy. The physical space sets limits to individual’s physical location within the organization and defines the parameters of the space an individual can legitimately access and appropriate for use (Ramphela, 1993: 4).

For instance, the time-space co-ordinates can be used to define what activities are appropriate or can be anticipated in a given organizational setting; thus shape what is possible within the confines of these co-ordinates. Scarcity of these physical and time resources suggest that the knowledge and pedagogy that can be made possible may have to meet these resource constraints requirements and as creativity is generally time-consuming, requires huge resource commitment and integrative work across and between disciplines; it can easily factor itself out of higher education strategic and operational positioning. Efforts on creativity development need to consider these issues very seriously if they stand a chance of succeeding. The political-economic space determines the framework within which the social relationships are conducted and legitimized through the ability or inability to marshal authoritative and allocative resources (Ramphela, 1993: 3). Institutional policies and budgeting on curriculum enactment set limits on choices that lecturers can make at the classroom level. As creativity is time and resource intensive, resource allocations and lecturer's zones of discretion can serve as important pointers on whether creativity is a legitimate institutional curriculum discourse.

The ideological-intellectual space provides a symbolic framework within which social interaction is conducted and is also the space within which norms are set for legitimate discourses (Ramphela, 1993: 5). The intellectual space refers to the capacity for critical awareness of one's environment and the position one occupies in the power structures of one's environment (Ramphela, 1993: 5) so that it assists individuals to demystify ideology and limit the impact of the constraints of a hegemonic order upon social relations. An ideology relates to an order in which a certain way of life and thought is dominant and is at its most effective when it remains interred in habit and has no need for words (Ramphela, 1993: 5). The dominant ideological assumptions in any social setting set limits and boundaries on discourse and thoughts and, often carry with them certain sanctions to enforce the notion of 'appropriate' spaces for the various members of a given social group or community. The ideological assumptions have the capacity to maim and silence and, research has that capacity to generate surplus power if not mitigated on a continuous basis (Pitso, 2009).

The psycho-social space is the 'inhabited space' that one finds oneself in which is mediated through certain cues by one's environment that encourage either the expansion or narrowing of one's expectations and aspirations within the institution which affects one's self-image and perceptions in a particular way (Ramphele, 1993: 7). The entrenched ways of doing within the institution under investigation and how it affects lecturers and students conceptions of creativity will be discussed in the chapters that follow particularly chapter seven and eight. Space and the key dimensions of creativity (product, process, people, domain and socio-organizational context) will be used in chapter seven and eight to identify and analyze the opportunities and constraints that are available in formal learning to encourage creativity.

Forrester and Hui (2007) review creativity within the Hong Kong educational settings and focus on what creativity in the classroom replaces. They view how curriculum reform attempts to move classroom learning away from the polarity of learning that is subject or skill-based and break down the compartmentalization of knowledge in order to encourage the development of creativity. Akin attempts to provide the necessary conditions for the successful development of design and creativity within engineering (Akin, 1990). He views the development of design and creativity in classrooms as dependent on shifting them away from seeking public recognition towards self-preservation. This implies a shift away from creativity that comes out with something new in relation to the whole of humanity towards creativity that enhances students' future effectiveness in the workplace and society. This is an important departure from cognitive traditions of conceptualizing creativity as the sole preserve of those endowed with special talent. The latter meaning of creativity falls within the framework of attempts on breaking down certain well-established ways of thinking and doing as strategies of fostering creativity (Forrester and Hui, 2007; Amabile, 1996; Cheng and Hui, 2002; Curriculum Development Council, 2001; Weiner, 2000). All these efforts to break the chain of entrenched ways of teaching and learning to encourage creativity are, I argue, efforts to challenge the apodictic ways of engineering education and hover closer to social dimensions of creativity.

These efforts, in summary, attempt to limit the following at a classroom level to attempt the development of creativity:

- Compartmentalized and subject/discipline-based approaches to learning including in design courses (Siu, 2000; 2002)
- Isolated learning of science and mathematics subjects (Cheung, 2002; Yip, 1998)
- Skill-oriented creativity strategies such as brainstorming and SWOT analysis (Hung, 2002).

In this sense, three issues stand out as pertinent in recreating alternative pedagogic practices that can encourage undergraduates' creativity development within formal learning – time, space and agency. However, in order to make better sense of the compartmentalization and isolation of subjects in formal learning as well as the strict timeline under which these subjects are taught, we can consider the theory of pedagogic practice developed by Basil Bernstein, based on the concepts of classification and framing. According to Bernstein's theory of pedagogic practice, classification refers to "*the degree of boundary maintenance between contents*" (Bernstein, 1973a: 205) which mainly concerns the insulation and boundaries between curricular categories such as knowledge areas and subjects. In applying his theory to curriculum, it is clear that a strong classification would refer to a curriculum that is highly differentiated and separated into traditional subjects. Based on this theory, it is palpable that classification plays a significant role in the organization of knowledge into curriculum, and thus becomes responsible for the curricular context that informs how such knowledge must be taught and learned. On the other hand, weak classification refers to a curriculum that is mostly integrated and whereby the boundaries between subjects are porous and fragile which, in turn, allow for external interaction between subjects and knowledge areas; this is what Dillon calls "*integrativism*" to refer to boundary crossings between subjects and knowledge areas (Dillon, 2006).

According to Dillon, such weak classification of curriculum to allow for cross-disciplinary studies and research may lead to the development of pedagogy of connection for working across and between disciplines. This, in turn, may facilitate students' development of creativity which tends to thrive on such weak knowledge classifications. Dillon's work on the pedagogy of connection is particularly relevant in the sense that he believes firmly in making educational interventions and using creativity tools within contexts and niches in which they are situated, and in developing learning environments that can afford change in how students learn to solve problems creatively.

While, in Bernstein's theory of pedagogic practice, classification mainly deals with how knowledge gets organized within the curriculum, framing relates to how knowledge gets transmitted through pedagogic practices. Framing thus refers to where and how control over the rules of communication in the classroom is located and thus, according to Bernstein (1990: 100), "*If classification regulates the voice of a category then framing regulates the form of its legitimate message*". This means that framing, in Bernstein's theory, refers to the extent and degree of control teacher and student possess over the selection, organization, pacing and timing of the knowledge to be transmitted in a particular subject and how it ought to be "*received in the pedagogical relationship*" (Bernstein, 1973b: 88). In this sense, a strong framing of the pedagogic practice is more likely to limit the options and freedoms available between the teacher and the students and a weak framing is more likely, by axiomatic deduction, to provide more opportunities for the teacher and the students to explore options and freedoms in the teaching and learning instances. Under conditions of a weak framing of the pedagogic practice, it is more likely that agentic power of both the teacher and students could be activated, and that sufficient leeway, by way of more time to work on curricular topics, may be provided. This is what Jardine (2008) calls "*whiling over*" curriculum topics, suggesting the value of time spent in the classroom where students are able to while over (take time to make sense of) a topic, work on it, compose it, such that remembering and cultivating their memories depend on interpretation rather than on acquisition.

This is the pedagogic practice I sought to develop in the *learnshops* in order to attempt to initiate and grow students into a particular creativity practice. It is thus not unreasonable to suggest, at this point, that at the core of creativity development within undergraduate studies is a sense of restoration of the principles of guided creativity, persistence and serendipity where the struggle over finding a solution to a non-routine problem compels one to while over the problem guided by certain emerging heuristics and experiences in creative problem-solving until the solution or important pointers are found. However, the gain in the use of heuristics and experience cannot be achieved by chance as it involves a deliberate effort to organize pedagogic practices in a particular way to allow for learning environments where guided creative problem-solving can thrive and students' initiatives and active participation in acts of resolving non-routine problems can be encouraged over time. The issue of guided creative problem-solving is expounded in the next chapter and issues related to agency, autonomy and the relationship between the teacher and the students are picked up and interrogated in more detail in chapter six.

In order to recreate alternative pedagogic practices that could modestly restore students' agentic power and release their thought and time spaces and thus, potentially, improve their creative abilities; this study used invitational pedagogy as the basis for framing *learnshops*. Invitational pedagogy is not new in science. While not widely covered in science and engineering education, the development of physics canon in the middle of the 18th Century in Germany involved students' experiments and students' presentation of their results to the physics community. The German physicist, Wilhelm Weber (1804-1891) became one of the first scientists and teacher to encourage students' active participation in physics through conducting experiments and sharing their findings in the classroom (Olesko, 2005). This Weberian approach to pedagogy is completely different from the practice of letting students to conduct experiments in the laboratory to confirm what the lecturer already knows or what is already confirmed as a fact in the textbook as is the tendency in UoTs, amounting to replication of those experiments (mimetic pedagogy).

Weberian innovative pedagogy's outstanding features were his focus, jointly with his students, on testing the reliability and sensitivity of a physics instrument, his concentration on the methods for measuring the earth's magnetism and his reliance on advanced students of physics to handle introductory students' learning (Olesko, 2005:326). Weber is also attributed with attempts to develop a more inclusive approach to learning physics that sought to accommodate students from all levels and from a variety of disciplines. By 1850, Weber was relying on peer mediation to pursue conceptual understanding of terrestrial magnetic measurements while he focused on the practical exercises on bifilar systems, the determination of the moment of inertia of a vibrating magnetic bar, theories of instruments and measuring absolute intensity and magnetic inclination and declination (Olesko, 2005:326). Weberian innovative pedagogy also ensured that those advanced students involved in peer mediation were also being prepared to conduct independent research projects.

Weberian pedagogic innovation, while laudable for allowing students some space for active participation and room for decision-making, was tainted by his insistence on research mentoring that was based on subordination and hierarchical delegation of authority and his belief on innate inclination and talent as determinants of students' science propensity (Olesko, 2005: 327-328). Weberian pedagogy also introduced peer assessment as Weber encouraged students to evaluate each other's data and discuss results in the seminars and practicals (Cahan, 1985).

However, it is Friedrich Kohlrausch (1840-1904) who was the student and later Weber's assistant at Gottingen Physical Institute who took innovative pedagogy to another level where issues of power were significantly reduced and collaboration between himself and the students and among students themselves was accentuated (Olesko, 2005: 328). Kohlrausch's approach to pedagogy is recognized largely because it inculcated social norms which science and physics tended to downplay. It is Kohlrausch who empowered students through making them partners in research and establishing guidelines for interacting with experienced and supporting members of the community.

He created the means through which students took part in their own learning and in educating others. The relationship between Kohlrausch and his students and among themselves was characterized by receptivity to criticism and a cooperative spirit (Olesko, 2005:328). Students, learning under this pedagogy, also learned to respect one another through including student-driven innovations in practical exercises. Of particular significance is the fact that the roles and responsibilities of the teacher and student were shared as the presentations rotated among them (Olesko, 2005:328). Under these learning circumstances, the line between teaching and learning blurred as students learned to present themselves and their topics as if they were “professionals”. In these presentations, advanced students participated not only as transmitters of knowledge but also in the creation and organization of knowledge. Kohlrauschian innovative pedagogy’s greatest contribution to pedagogy is the role it accorded both the teacher and the advanced students as partners in research so that there was a temporary fusion of their identities as researchers (Olesko, 2005:329).

The environment under which this pedagogy thrived was invitational rather than conquest or conversion-based both of which have the intention to change others’ position on a matter. It is Kohlrauschian innovative pedagogy that was attempted in the *learnshops* to provide opportunities for students to learn in a research and collaborative mode. However, the study went one step further in terms of innovative pedagogy by adding the problem-solving imperative in the *learnshops* so that *learnshops*’ pedagogy assumed an invitational character because it created conditions where students were given opportunities to solve real, practical problems that seasoned engineering experts are grappling with rather than working within the framework of “expert solved problems” that encourage mimetic pedagogy. Students were given time and space in the *learnshops* to attempt real solutions to real problems, and thus the right to exercise their active agentic power. Table 2.1, below gives a summary of these pedagogic paradigms. Invitational pedagogic agentic power resides in Bernstein’s theory of pedagogic practice, especially the notion of weak framing to renegotiate the classroom thought and time spaces since weak framing in the classroom implies freedom and greater discretion for the actors.

	<i>Time</i>	<i>Space</i>	<i>Agency</i>	<i>Epistemic Beliefs</i>	<i>Classroom Procedures</i>
Mimetic	Strict	Closed-ended	Passive-active	Foundational, dualistic, neat and universal, strong curricular classification	Deficit-driven, general faculty, drill and practice, conceptual understanding, Strong framing (limited freedom and options)
Invitational	Flexible	Open-ended	Active-active	Foundational, Relative, contextual, local with universal appeal, weak curricular classification	Research and collaborative mode, teamwork (group dynamics), communication (invitational) safe conversations, aligned intent, willingness to share ideas, shared mental models, collective decisions, weak framing (sufficient freedom to exercise agentic and discretionary power)

Table 2.1: *Pedagogical Paradigms*

The weak framing in curricular and pedagogic transformation suggests that transformation is possible when people are exposed to opportunities to exercise their freedoms in teaching and learning. In other words, the process of transformation should almost always begin with the opening up of the space for engagement and allowing both classroom actors sufficient leeway to experiment and deal effectively with areas of legitimate uncertainty (Perry, 1970). However, it is imperative that in managing progressive change, change agents should show willingness to learn from others (distributed tentativeness), work towards shared meaning and goals (aligned intent), create safe conversations in which actors have a sense of feeling wanted and valued (genuine dialogic reconstruction) as well as maintain respect all the time (sensitiveness).

Distributed tentativeness, aligned intent, genuine dialogic reconstruction and sensitiveness are at the heart of invitational pedagogy and are vital in classroom situations where both classroom actors have sufficient leeway to exercise freedom in teaching and learning away from the asphyxiating and limiting conditions of didacticism. Didacticism gives power to institutions to decide on what must be taught and how it should be taught as well as proceeds on the basis of delegated power to the teacher who must exercise it over the students to achieve pre-determined outcomes.

In conclusion, engineering education has begun a process of developing alternative curricular and pedagogic conditions that can enhance students' creative abilities through making linkages between the nature of knowledge embedded in curriculum content and its strong tendency to encourage certain pedagogic practices. For instance, a curriculum that signifies learning content that has wide applicability and is based on strong classification (Bernstein, 1990) tends to encourage the pedagogic practices that compel the teaching and learning of existing knowledge by means of mimesis and 'copying'. A curriculum that considers knowledge as context-based and is weakly classified (Bernstein, 1990), on the other hand, does not necessarily discard universal, existing knowledge but insists on its localization to contribute in resolving real, practical problems embedded in those contexts thus is more likely to compel students not only to use the general knowledge they gained but also problematize it to deal effectively with challenges at hand.

Another body of literature in engineering education focuses on how to assess students' creativity especially as measures of determining whether an educational or training programme has succeeded in fostering creativity. Baillie and Walker (1998) used different assessment methods in each of the three case studies they presented to determine whether each of these case studies achieved what each set out to achieve.

For instance, the Professional Engineering Programme was designed to improve Mechanical Engineering undergraduate students' thinking abilities by means of activities that included group-work, discussions, debates, communication exercises and industrial visits (Baillie and Walker, 1998). In order to find out whether this programme worked, they used a report-writing assessment method which was graded according to the SOLO taxonomy (Biggs and Collis, 1980) to ensure quality of assessment.

Similarly, Chen, Jiang and Hsu (2005) designed a Creativity-Enhancing Program within the Industrial Engineering and Management curriculum and the Torrance's Tests of Creative Thinking (TTCT) were used to measure changes in the students' creativity. Chang and Hsiao (2002) used students' portfolios to assess teamwork in Project-Based Learning in a programme designed to improve students' engineering professional skills. Slightly different from the assessment methods used to assess students' creativity in Electrical and Mechanical Engineering, Mathews and Jahanian (1999) used a team of experts to achieve such a goal while Mitchell (1998) made use of peer assessment to judge students' creativity. A completely different set of assessment infrastructure is used to determine the effectiveness of the training programmes on fostering creativity. Each set of assessment is designed in such a way as to measure a specific area of creativity. Kauffman (2002) focused on assessing the correlation between creativity and the development of new social institutions. Amabile (1997) assessed the role of creativity in enhancing entrepreneurial activities and long-term economic growth whereas Ensor, Cottam and Band (2001) focused on the role of creativity in enhancing the work profile of job-seekers in an information-based economy. King and Anderson (1990) paid attention on the assessment of the effectiveness of structuring group interactions. This study employed the TTCT to measure the change in students' creative abilities. Furthermore, in this study, the basis of case studies is sustainability in the context of engineering. I consider sustainability as a necessary condition for engineering work alongside usefulness, *techné* and praxis (Pitso, 2008). Case studies, thus, were intended to provide students with opportunities to view technologies as problematic on the strength that when these technologies were designed they were premised on the industrial age anthropocentric view of nature.

This view posits that nature has unlimited and unfettered abundance with little focus on the impact of such a view on the sustainability of natural resources. The 21st Century is based on the post-anthropocentric view of nature (Korten, 1995) which centres engineering work and technological development and innovation on sustainability of natural resources hence sustainability has to be seen as the pivot around which case studies as aspects of *learnshops* oscillate.

Summary

Three levels of broad conceptualizations of creativity have been presented in such a manner as to provide a rough timeline through which these conceptions of creativity emerged. Creativity was originally conceived of as an individual issue imprinted during birth which thus required no form of assistance from the environment. This view of creativity defined it as being generally impossible to enhance through the structures of formal education and was closely associated with the measurement of intelligence. This position on creativity could, however, not be sustained in engineering as the design and building of complex technologies depended on the technical skills of various engineers who were nevertheless expected to collaborate and work in teams as they shared and learned from one another. This view of creativity was conceived at an individual level but quite vulnerable to the influence of the social context hence it was later termed socio-cognitive perspective on creativity. In research, this position on creativity was dominated by expert teams and how they developed new schemas of understanding and sharing.

The last position on creativity focused on how learning environments can be intentionally and deliberately altered to encourage the growth and development creativity through a research and collaborative mode. This view of creativity, which assumes a social perspective on creativity, locates itself in formal learning and has been preoccupying engineering education over the last two decades and forms the basis of this study.