AC 2009-1195: THE INTEGRATION OF COGNITIVE INSTRUCTIONS AND PROBLEM/PROJECT-BASED LEARNING INTO THE CIVIL ENGINEERING CURRICULUM TO CULTIVATE CREATIVITY AND SELF-DIRECTED LEARNING SKILLS

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Integration of Cognitive Instructions and Problem/Project-Based Learning into Civil Engineering Curriculum to Cultivate Creativity and Self-Directed Learning Skills

Abstract

Creativity and Self-Directed Learning involve higher order metacognitive (or executive) processes and are essentially interconnected. The attitudes and skills that embrace creativity and self-directed learning are specified explicitly or implicitly in the 2nd Edition of Civil Engineering Body of Knowledge (BOK2). However, traditional engineering education has paid less attention to deliberately cultivating students' metacogntion development with explicit instructions based on effective theoretical frameworks from Cognitive Science and Educational Psychology. The efforts of engineering faculty members for helping students to develop their creativity and self-directed learning skills may consequently be minimized. This paper reveals conceptual models of creativity and self-directed learning, as well as motivation, from cognitive science literatures, and explores a new pedagogical model that is built on related theoretical framework and education practice and could be transferable for incorporating BOK2 requirements into civil engineering curricula. The development and implementation of the proposed pedagogical model are presented.

Cognitive science literatures suggest that effective development of metacognition requires obtaining not only metacognition knowledge and strategies, but also metacognition control experience over specific cognitive tasks through efforts driven by intrinsic motivation. The creativity and self-regulated learning are essentially interacted attributes and can result in optimal performance and self-efficacy (or confidence), and in return help forming positive attitudes and enhancing intrinsic motivation, which lead to persistent efforts for pursuing further self-directed learning and creativity. There is a synergic cycles among these attributes. Based on cognitive theoretical frameworks, a new Pedagogical Model is proposed to integrate new Cognitive Instruction Model and Problem/Project-Based learning into co-curricular design projects, in which motivation, self-regulated learning, and creativity are synergized to cultivate desirable skills of self-regulated learning and innovative problem-solving for engineering students.

The proposed Pedagogical Model has been developed from and integrated into a co-curricular design project in a mainstream civil engineering course through Nanotechnology Undergraduate Education project. The implementation outcomes indicate that all students participated in Problem/Project-Based learning and communicated more with instructors for advice and feedbacks. Most of students were motivated by the intellectual challenge of the course project and actively engaged in their self-directed learning of emerging technology and innovation. They gave positive comments on their experience. The implementation outcomes suggest that the proposed Pedagogical Model can be suitable for involving students in self-directed learning and creativity processes and promoting effective inquiry and use of strategies for development of students' metacognitive skills in creative thinking and self-directed learning. Future improvement on the implementation of the proposed Pedagogical Model is also discussed.

Introduction

Metacognition is often simply defined as "thinking about thinking", and refers to the awareness of and reflection upon how one learn knowledge and how one use information to achieve a goal, and the ability to judge and meet the cognitive demands of a particular assignment[1,2]. It is higher-order self-regulated mental processes that include making plans for learning, using appropriate strategies to solve a problem, and evaluating performance and learning[3]. Metacognition is essential for a successful learner and effective problem-solver. Both creativity and self-directed learning involve higher order metacognitive processes. The attitudes and skills that embrace creativity and self-directed learning are specified explicitly or implicitly in the Vision for Civil Engineering in 2025 (Vision 2025) by ASCE and BOK2 for future civil engineers.

Vision 2025 is the basis for BOK2 and outlines a global vision for civil engineers in the future. It emphasizes that civil engineers are "entrusted by society to create a sustainable world and enhance the global quality of life", and need to "serve competently, collaboratively, and ethically as master of **innovators** and **integrators** of ideas and technology across the public, private, and academic sectors". The Vision 2025 also prescribes that a range of attitudes that supplement knowledge and skills for *a* successful civil engineer to embrace for effective professional practice. These attitudes will manifest themselves in several aspects, such as "**creativity** and **entrepreneurship** that lead to a proactive recognition of opportunities and subsequent actions to take advantage of them"; "**Curiosity**, which is a basis for **continued learning**, fresh approaches, development of new technology or **innovative applications** of existing technology, and new endeavors"; and "**Optimism** in the face of challenges and setbacks, recognizing the power inherent in vision, commitment, planning."

BOK2 primarily focuses on what should be taught to and learned by future civil engineering students, and particularly defines the knowledge, skills, and attitude necessary to be a licensed professional engineer to new challenges of the 21st century. The 24 outcomes specified by BOK2 include following outcomes that emphasize higher order executive skills of problem-solving, innovative design, and lifelong learning by possessing self-directed learning ability.

Outcome 8: Problem recognition and solving – "Formulate and solve an ill-defined engineering problem appropriate to civil engineering by selecting and applying appropriate techniques and tools". "Civil engineers are expected to anticipate and identify problems and opportunities in various systems and environments".

Outcome 9: Design – "Evaluate the design of a complex system, component, or process and assess compliance with customary standards of practice, user's and project's needs, and relevant constraints." "Defining the scope and design objectives and identifying the constraints governing a particular problem are essential to the design process. The design process is open-ended and involves a number of likely correct solutions, including innovative approaches" (The commentary on outcome of design in the first version of BOK further states that critical design methodology and process elements include problem definition and creativity).

Outcome 23: Lifelong learning – "Plan and execute the acquisition of required expertise appropriate for professional practice". Civil engineering graduates must "demonstrate the ability

for self-directed learning, and develop their own learning plan". "Self-directed learning is a mode of lifelong learning because it is the ability to learn on one's own with the aid of formal education".

In addition, the BOK2's guidance for students and engineer interns requires them able to understand the vision for civil engineering, develop horizontal thinking, self-direct life, and able to reflect, plan, and act. The guidance provided by BOK2 also requires faculty to creating intellectual excitement for students and motivate them by active involvement in their personal learning process.

However, traditional engineering has paid less attention to deliberately cultivating students' metacognition development with explicit instructions based on effective theoretical frameworks from Cognitive Science and Educational Psychology. It remains up to individual students to make their metacognition development as by-products of their engineering education. Even though many engineering faculty members have recognized that creativity and self-directed learning skill are important for students, most of them may not be aware of and utilize the research development from Cognitive Science that can provide the guidance for such metacognition development. Their efforts to help their students develop these skills may consequently be less effective than they might expect.

The objectives of this paper is to introduce the theoretical framework of matacognition and conceptual models of creativity, self-regulated learning, and motivation from cognitive science literatures; and to share a pedagogical model and educational practice that incorporate the development of creativity and self-directed learning skills into civil engineering curricula. Literature reviews across cognitive science is first presented. Then, a Pedagogical Model is proposed to integrate Problem/Project-Based Learning with new Cognitive Instruction Model into co-curricular design project. The development and implementation of the proposed Pedagogical Model in a mainstream civil engineering curriculum and its outcomes are revealed and their further improvements are discussed. Implementation outcomes suggest that the proposed Pedagogical Model could be suitable for involving students to acquire metacognitive knowledge and promote practice of metacongitive strategies, and has a potential for leading to development of attitudes and skills for self-directed learning and creativity.

Literature Review - Theoretical and Methodological Background of Proposed Pedagogical Model for Engineering Education

Research development from Cognitive Science and Educational Psychology provides scientific frameworks for metocognitive attributes, their influential factors and correlations with each other attributes, and can serve as methodological frameworks for engineering faculty to develop effective instructions for facilitating and coaching their students' metacognition development. Awareness and understanding of these conceptual models of metacognitive attributes is a prerequisite for both faculty and students to engage in their own efforts for enhancing students' metacognition.

In following literature reviews, the framework of metacognition and its correlation with both motivation and utilization of strategies are first presented. It can serve as an overall theoretical

framework for the proposed Pedagogical Model and other metacognitive attributes discussed in this paper. Then, the conceptual models of self-regulated learning and creativity are examined and constructed within the theoretical framework of metacognition. The correlation between creativity and self-regulated learning is revealed. In addition, the conceptual model of motivation are also examined and utilized as the important driving force for the development of desirable attitudes and skills. The connection between constructive attitudes and optimal experience from creativity and self-regulated learning is justified. Based on these theoretical framework and conceptual models, a Pedagogical Model is proposed to integrate Problem/Project-Based Learning with new Cognitive Instruction Model into a co-curricular design project, in which motivation, self-directed learning, and creativity are synergized to cultivate constructive attitude and innovative problem-solving skills for engineering students.

Metacognition

Researchers have distinguished between two main components of metacognition: *metacognitive knowledge* and *metacognitive experience*[2]. Metacognitive knowledge refers to acquired knowledge about cognitive processes and strategies that can be used to control cognitive processes. Metacognitive experiences refer to activities that control one's thinking and learning and involve the use of metacognitive strategies and metacognitive regulation[2]. Metacognitive strategies are sequential processes that one uses to control cognitive activities and to ensure that a cognitive goal has been met. These processes help regulating and overseeing learning and consist of planning and monitoring cognitive activities, as well as evaluating the outcomes of those activities.

Research has shown that the most effective approaches to metacognitive instruction involve providing the learner with both metacognitive knowledge and metacognitive experience (or practice) in using cognition strategies and evaluating the outcomes of their efforts. Simply providing metacognitive experience without metacognitive knowledge or vice versa does not seem to be sufficient for the development of metacognitive control[4]. In addition, the metacognitive experience must be incorporated into specific cognitive tasks or the domain subject that students are learning. Attempts to teach metacognition as generic skills can lead to failure to transfer them into other specific learning domains [4].

It has been well documented that students provided with proper metacognitive instruction that is integrated into their learning tasks are likely to improve their performance much more than students who do not receive metacognitive training. The effective approaches to effective metacognitive instruction, even if administered for a short time in addition to task-based training, can improve students' performance considerably [5, 6, 7,8]. These performances can in turn lead to improved perceptions of self-efficacy (or confidence). The research has shown that self-efficacy is highly correlated with student performance and activities with clearly defined goals [9,10,11].

Self-Regulated Learning and Its Tie to Metacognition

Combination of the above two metacognition components in learning process involves: examining both new knowledge and existing knowledge; establishing connection between new knowledge and existing knowledge; deliberately selecting and monitoring thinking strategies; and evaluating cognitive processes[12]. In this regard, metacognition is tied to self-directed

learning or self-regulation in learning. Zimmerman has determined three important components of self-regulation, including strategies for goal-setting and organization, a self-oriented feedback loop process, and recognition of the necessity of preparation and effort [9,10]. He had proposed three phases to Self-Regulated Learning, which include planning, monitoring, and self-reflection.

Self-Regulated Learning (SRL) has become a research subject and educational practice in the context of Educational Psychology. The model of self-regulated learning has been developed through research and practice, and involves self-monitoring and self-correction of three aspects of learning: self-regulation of motivation, behavior, and cognition. SRL refers to active learning that is guided by three aspects of learning: (1) motivation to learn; (2) metacognition (i.e., awareness of one's knowledge and beliefs); and (3) strategic action (i.e., planning, monitoring, and evaluating personal progress, and taking proper action) [9,10,13]. The important SRL strategies include identifying and utilizing resources.

Self-Regulated Learning is essentially a metacognitive process for performing specific cognitive tasks with emphasis on self-regulated motivation for acquiring metacognitive knowledge and metacognitive regulation over the cognitive tasks. The latter two are two basic complements of metacognition. A wealth of research has supported that optimal academic performance is strongly tied to the extent to which the learner uses SRL[9,10]. Equipping students with SRL abilities not only contributes to success in formal education, but also prepares them for lifelong learning [14]. Nonetheless, SRL is not well known and utilized by the STEM education community for facilitating student learning in STEM.

Creativity

Research on creativity has established conceptual models that reveal the attributes and influential factors for the creativity. Although the definition of creativity is frequently varied, there is some consensus that it deals with a ''process'' which results in a ''novel product'' that involves the introduction of new variables, significant leaps, and novel connections [15,16]. Innovation as a subset of creativity not only involves the creation of a new idea but also involves its implementation, adoption, and transfer for solving problems[16]. From a process perspective, creativity involves utilization of the social, cognitive, and thinking strategies, as well as physical action that controls processes situated in individual, team, and organization contexts [16]. Well-accepted perception on creativity includes Originality, i.e., how one idea can advance existing ones; Idea Fluency, i.e., how many ideas have been generated; and Flexibility, i.e. how many different approaches have been considered [17,18].

Most of established models on creativity can be characterized with Amablie's creativity model. Amabile has created a social psychology model of creativity, which contains three components within the individual: intrinsic motivation, domain knowledge, and creative skills (or strategies), and the fourth component from environment, e.g. external setting, extrinsic motivation, rewards, social interactions, and time pressure [19]. Amabile further identified six environmental stimulants of creativity: Freedom, positive challenge, supervisory encouragement, group support, organizational encouragement, and sufficient resources [20]. Two environmental obstacles to creativity were also identified as organizational impediments and excessive workload stress [20].

Csikszentmihalyi has developed a systematic perspective on creativity that emphasizes the environmental component of Amabile's model. He emphasized that creativity takes place in the context of well-established resources. Learning and creativity can be facilitated by optimal experience, which includes facing challenges that match to skills, a merging of action and awareness, clear goals and feedback, feeling of control, and intense concentration and absorption [21,22].

In addition to external environment components, research on creative individuals has shown that it is the intrinsic motivation that makes creative people work so hard for their potential creativity. Even though domain knowledge and thinking skills (or strategies) are important for creativity, the intrinsic motivation is more critical for creativity. Creative individuals indicated their intrinsic motivation for creativity is tied to their desire to improve their personal well-being [23]. Thus, Torrance who is renowned as "the father of creativity" advocated self-actualization for well-being as motivation for creativity as a preventative measure at an early age. He believed that every person should develop the beliefs that he can do some sort of original work. If these beliefs were cultivated early, there would not be so many adults who sense futility about doing something original [17,18].

Creativity Process and Its Construct under Metacognition Framework

The role of metacognition in creativity has been explored by several researchers. For example, the idea of "metacreativity" has proposed by Bruch [23]. Metacreativity examines how and what to do in creative processes and includes choosing a creative strategies and reflection on one's mind and thoughts during the creative processes. It has similar characters as metacogniton and can be regarded as metacognition related to the creative process, although it differs from metacognition. Pesut proposed a creative thinking model as a metacognitive process. He reframed creativity technologies as metacognitive strategies and viewed creativity as a self-regulatory process of utilizing metacognitive knowledge and metacognitive regulation that includes combination of self-reinforcement, self-evaluation, and self-monitoring [24].

A wealth of creative thinking strategies has been developed to guide creative thinking and innovative problem-solving. These strategies can be fitted into the metacongition framework as metacognition knowlwdge and strategies for creative processes. For examples, three basic principles of creativity states: (1) New ideas are composed of old elements; (2) Not all new ideas are useful; and (3) Creativity is enhanced by the ability to detect connections between ideas [25]. Wallis Model of the Creative Process describes four-stage of creative process, i.e. Preparation, Incubation, Illumination, and Verification [26]. Altshuller studied thousands of patents and the way in which the innovation had taken place, and established Theory of Inventive Problem Solving (TRIZ, a Russian acronym) [27]. TRIZ includes 40 Principles of Invention, several Laws of Technical Systems Evolution. These Principles and Laws are being applied to solve creative invention problems within technical and non-technical fields.

Two main thinking strategies in the creative process have been identified by Guilford as Divergent Thinking that is concerned with the review of ideas and solutions with maximal openness and the avoidance of premature judgment; and Convergent Thinking that uses mainly knowledge, analysis and judgment to find the most suitable solution[28]. De Bono made a similar

distinction between Lateral (or horizontal) Thinking and Vertical Thinking [29,30]. While traditional education emphasizes Vertical Thinking, Lateral Thinking can move simultaneously in different directions. He has developed three distinct thinking methods: Six Thinking Hats (or six styles of thinking); Lateral Thinking; and Direct Attention Thinking Tools. Dieter described the various creative strategies of brainstorming, force-fitting, mind-mapping, synthesis and transformation (or analogy), virtual thinking [31].

As students are provided and equipped with multiple thinking tools or strategies for creativity and engage themselves in creative processes to use these tools and strategies, they can have an opportunity to develop their capacity to apply the various modes of thinking to the problems and judge which ones are most appropriate. As results, they can have experience to think about what they are thinking while they are thinking and consider what appropriate strategy should be used. In this sense, students' metacognitive processes can be triggered and their metacogntion development can be promoted[32]. Thus, creativity education or training can lead to metacognition development for engineering students and can be constructed within the framework of metacognition.

Interaction between Creativity and active Self-Directed Learning

The literature reviews support that creativity and self-directed learning are interconnected to each other. The interaction between creativity and self-directed learning lies in two ways. On one hand, creativity can enhance metacogntion as mentioned in the above and benefit active self-directed learning. Constructionism developed by Papert has been well accepted as both a theory of learning and a strategy for education. It emphasizes that learning is active (vs. passive) knowledge construction process through experience, particularly through creating and experimenting, which involves establishing the connection between learners' new knowledge and their own existing knowledge, and imagining applications of new knowledge in different situation in the future[33].

Creativity could benefit active learning in creating connections and imagining application for knowledge building-up and application in the three aspects: originality (i.e., new connections and imaginations); fluency (i.e., many connections and immigrations), and flexibility (i.e., different types of connections and imaginations) for building knowledge and solving problems through using knowledge. Kay advocated learners to actively question the 'facts' and strive for new challenges and ''knowledge ownership'', and believes that the deep joy brought by learning itself and the innovative ways of thinking can enormously expand understanding and learning [34].

On another hand, there is a general consensus that effective self-directed (regulated) learning is essential for and directly linked to creativity. Minsky revealed that the processes that the most creative people engage in include two approaches, the manner in which they can learn more and deeper skills, and the manner in which they learn to manage these skills[35]. Behind their expertise, creative people may often have developed advanced executive or self-regulated skills that provide a better framework for utilizing and structuring their skills and learning. Due to this combination of this conscious or subconscious meta-cognitive manager, creative people are better self-directed learners, because they know better ways of choosing how and what to learn. The "quick learning" or "learning as needed" techniques through self-directed learning have

been used by large number of inventors[23]. This indicated creative people are effective self-directed learners.

Motivation

Presenting cognitive and metacognitive strategies and experience opportunity to students does not guarantee their metacognitive development and achievement, because implementation of these strategies is not an easily task and needs persistent efforts. Both creativity and self-regulated learning needs strong intrinsic motivation and self-regulation of such motivation. Thus, students must have motivation and awareness of regulation of such motivation to use the strategies and regulate their efforts for creativity and self-regulated learning.

A conceptual model of motivation proposed by Pintrich can be used to address the students' motivation. The model contains three components: (1) self-efficacy, which is an individual's belief and confidence in their ability to accomplish goals; (2) task value, which is an individual's perception of importance of a task, personal interest in the task, and perception of the utility value of the task for future goals; and (3) goal orientation, which includes mastery goal orientation referring to concern with learning and mastering the task using self-set standards and self-improvement [36]. Thus, efforts for enhancing motivation in pursing creativity and self-regulated learning have to concern about the above three components.

This model reveals that motivation is tied to self-efficacy (or confidence), which can only be cultivated with high involvement and achievement through successful experience in learning and problem-solving. Motivation can be enhanced and sustained by increasing task value and setting mastery goal orientation, which can be achieved through the value and utilization of outcomes from creativity and self-directed learning. In return, motivation can further drive ones efforts to pursue creativity and self-directed learning. Thus, there is synergy among self-directed learning, creativity, and motivation.

The available literatures suggest there is synergy and interaction among creativity, self-directed learning, and motivation[14]. Thus, there is a potential to use creativity education not only to enhance students' creative thinking, but also develop student's metacognition and self-regulated learning skills, and lead to the improvement of their self-efficacy (or confidence), learning motivation, academic performance. Students' motivation can be conceptualized and cultivated using a theoretical framework of the general motivation, and can be incorporated into new learning materials in the new proposed Cognitive Instruction Model.

Related Pedagogies and Practice in Education

Problem-Based Learning (PBL) was developed from medical professional training and has been used as a student-centered active learning pedagogy[37]. It now represents a greater paradigm shift of traditional education [32,38]. Ill-defined problems are a key aspect of PBL and allow students to undergo a process of problem identification. Through such processes, students may define a problem themselves in a way that not only engages them but also is relevant to their particular learning interest, level, and style. This allows freedom and grants the ownership of students' learning activity. Project-based learning may be defined in various ways, but many of its

outcomes are similar to learning outcomes claimed for problem-based learning. Problem-Based Learning is often exchangeable with Project-Based Learning (PBL) in application. PBL essentially embraces the use of metacognition and self-regulation [38]. PBL develops problem solving skills by enabling students to transfer the problem-solving strategies to a similar problem on a related topic [39]. Tan and Ee observed that cognition, metacognition and self-regulation characterize effective PBL [40]. Awang and Chung found that PBL promotes creativity and ability to apply metacognitive strategies [41,42].

To promote students' Self-Regulated Learning (SRL) skills, Somuncuoglu and Yildirim recommend that metacognitive strategies in SRL can be specifically emphasized by incorporating self-regulated course activities that raise the students' awareness of planning (setting learning goals), monitoring (self-testing or evaluating), and regulating (determine best way to learn)[43]. Celuch and Slama have given students assignments based on the above recommendations to stimulate students' self-regulated learning. The learning benefits of these assignments have been favorably assessed[44]. Blank et al. developed a self-assessment-for-learning approach. Through a series of self-assessment questionnaires as instructional cues embedded in class quizzes, students were promoted to track and assess more effectively their academic learning. These self-assessment questionnaires simulate three phases of SRL model [9,10] in series of self-directed feedback cycles. Through deliberate practice with SRL instructional cues, students become more skilled at using both metacognitive and external feedback to continuously adjust and improve their learning efforts[45].

Creativity education programs have been carried out in engineering education. Most of these programs typically focuses on various idea-generation techniques and procedures, and integrates these techniques and procedures into student design projects. Ogot, Okudan, and Shields (2007) have introduced Theory of Inventive Problem Solving (or TRIZ) into core engineering courses [46,47]. Ocon adopted issued-based learning to introduce creativity and creative techniques [48]. Awang and Ramly integrated Problem-Based Learning with creative thinking into an engineering course[41]. Bailie introduced four-stage procedures for creativity: preparation, generation, incubation and verification, to facilitate students to innovatively deign composite and infrastructures [49]. University of Virginia offers series of courses designed to stimulate creativity through conveying attitudes and beliefs, thought pattern, habits and behavior characteristic of creative people and teams [50].

In a broader scope beyond engineering education, MIT and Buffalo State University offer a creativity course for students from all disciplines. At UC-Berkeley, undergraduates and graduates from multidiscipline form Berkeley Innovation Group and cross-pollinate ideas for innovative solutions that will improve student lives in and around Berkeley. The Creative Problem Solving Method (CPS) developed by the Center for Creative Learning is deemed as one of few holistic creativity programs in existence [32]. CPS is mostly used to promote creative thinking at K-12 levels and addresses three broad areas in development of creative solutions: (1) Deliberate use of process and tools to solve problems; (2) Consideration of dynamics in the environment/climate; and (3) Consideration of personal problem-solving. This program emphasizes to trigger students metacognition by providing them with multiple thinking tools and strategies and engaging in a challenge.

However, existing creativity education programs lack emphasis on the components involved in the creativity process, such as motivation, freedom, ownership, self-regulated learning, and metacogntion, which are necessary for cultivating creativity. There were also lack of deliberation on utilizing the synergy between creativity and self-directed learning, as well as lack of explicit Cognitive Instruction Model constructed within metacogntion framework for facilitating students' creativity and self-directed learning processes. The proposed Pedagogical Model in this paper strives to address these important aspects in the creativity in the engineering education settings, and is built on the literature reviews and authors' practice in cultivating creativity and self-regulated learning for engineering students.

Proposed Conceptual Framework of Pedagogical Model (PM)

While the Problem/Project-Based Learning (PBL) is a student-centered inquiry-based active learning pedagogy developed from professional training practice[37], it lacks systematically-defined cognitive instruction framework for guiding and regulating students' motivation, strategies utilization, action, and reflection during their cognitive process. The theoretical framework of metacognition and synergy among creativity, self-directed learning, and motivation are unitized to develop a new Cognitive Instructional Model (CIM) for guiding Problem/Project-Based Learning process.

The proposed Pedagogical Model (PM) is intended to cultivate creativity and self-directed learning skill and lead to higher metacognition development for engineering students. This Pedagogical Model (PM) integrates the new Cognitive Instructional Model (CIM) and Problem/Project-Based Learning through a co-curricular design project. It includes following four components that could facilitate self-directed learning and creativity:
- Suitable learning setting and experience through early assignment of the course project that allows students have sufficient time and less time pressure to cultivate creativity and self-regulated learning;
- Students' autonomy for selecting design subject and learning that match their interest and current ability, allow freedom and grant ownership of their learning process, and motivate their persistent efforts for active learning;
- Comprehensive resource of declarative knowledge and thinking strategies for creativity and self-regulated learning that are available to students as they need;
- Cognitive instruction for guiding the processes and promoting reflection based on the proposed holistic Cognitive Instruction Model of Self-Regulated Leaning and Creativity Process as presented in following.

Among existing cognitive instructional model, the Self-Regulated Learning model emphasizes self-reflection and self-regulation of three aspects of learning: motivation, metacogntion, and strategic action [9,10]. While the Self-Regulated Creative Thinking model emphasizes regulation and action in the creativity, but does not emphasize important aspects of creativity: regulation of motivation and self-directed learning[24]. Based on the synergy among creativity, self-regulated leaning, and motivation, it would be logical to unify all relevant components in the creativity and self-regulated learning processes under the framework of metacognition and form a new holistic Cognitive Instructional Model (CIM) of Self-Regulated Learning and Creativity (SRLC) Process model.

Self-Regulated Learning and Creativity (SRLC) Process model is then defined as learning and creative problem-solving processes and involves self-monitoring and self-correction of following three aspects in creativity and self-directed learning:

- Motivation: related to self-actualization including personal pursuit of well being, passion, and extended to overcoming frustration due to failure, and maintaining optimal emotion and mode.
- Metacognition: including awareness of one's beliefs on learning and creativity, and metacognitive knowledge of the following interrelated parts: (a) knowledge of one's own cognition and creativity process; (b) knowledge about the specific cognitive and creative strategies that might be used for various learning and creativity tasks, particularly including strategies for strengthening personal beliefs and persistence for efforts; and (c) procedural knowledge of when and where to use acquired strategies.
- Strategic action: personalized planning, identification of resources, monitoring, and evaluating and reflecting personal progress, and taking proper action, including action on controlling motivation, emotion, and mode, regulating learning beliefs.

Fig. 1 Conceptual Model of SRCP Four-Phase Implementing and Feedback Cycles

The model process of SRLC is built on well-established self-regulated learning three phase process of repeated cyclic model. However, the awareness of available action strategies and thinking tools, as well as other resources, are important in metacognitive process. Thus, the Identification of Resource is isolated from planning phase of typical three phase Self-regulated Learning Model and regarded as an important independent phase in SRLC process model. The four phases SRLC process model in repeated cycles is proposed and presented in the conceptual model (see Fig. 1), and used to guide the creativity and self-regulated learning process for Problem/Project-Based Learning.

Integration of Proposed Pedagogical Model (PM) into Existing Curriculum

The proposed Pedagogical Model (PM) was initiated for one of ten new course modules in Nanotechnology Undergraduate Education (NUE) project, and implemented in a mainstream civil engineering course Construction Materials and Lab not only at Jackson State University in

2007 and 2008, but also at the University of Oklahoma in 2007 and the University of Houston in 2008 respectively. It has been developed by authors over last two year period in the repeated feedback-improvement cycles same as SRLC processes, i.e., from planning and designing, identifying resources and strategies, monitoring and evaluating, and reflecting and improving in the first year, to re-planning and re-designing as the beginning of the next cycle for the second year.

The overall goal of the NUE project is to convey a new vision of civil engineering with nanotechnology innovation and create diverse new learning opportunity for students majoring in civil engineering, mechanical engineering, and technology. The project has developed ten new course and lab modules related to nanotechnology applications in civil engineering, and integrated them into existing civil engineering curriculum and other engineering/technology courses. The scope of the NUE project and ten new course modules can be found somewhere else[55]. The specific objective of the New Course Module on Creative Thinking and Creativity through Problem/Project-Based Learning for Innovative Design is to provide a platform for students to

- engage in the active learning nanotechnology innovation throughout the new course module implementation and self-directed learning;
- practice strategies for self-directed learning and creativity;
- apply the knowledge of nanotechnology learnt from new course modules and self-directed learning;
- explore students' potential for innovation;
- experience enjoyment from the accomplishment from creativity and self-directed learning.

The co-curricular design project was carried out through Problem/Project-Based Learning and assigned to students early at the beginning of the course. Students were given autonomy to choose the subject related to their field or interest for the design project. They were required to identify and innovatively solve a problem in civil engineering or design a novel infrastructure through applying emerging nanotechnology, such as nanotechnology-enabled multiple-functional materials, devices, or combination of them, and report their project in final presentations with following aspects:

- Proper presentation format (10 points)
- Problem description (20 points)
- State of Previous work or solution by others (10 points)
- Innovative solution and how it is built on the previous works (30 points)
- How the solution utilizes and relates to nanotechnology (10 points)
- How the innovation is initiated or inspired or what strategies are utilized for your innovation (10 points)
- Reference cited (10 points)

The instructors facilitated students' Problem/Project-Based Learning activities by providing fundamental knowledge, background information, inspiration for creativity, and supportive feedback for students' active inquiry learning. The fundamentals of nontechnology and examples of its innovative application for civil infrastructures were presented in the subsequent new course modules. Comprehensive references on nanotechnology application were also provided to

students. The selected example application exemplifies strategies for innovation, e.g. *Creativity through Transformation* and *Innovation through Synthesis*, including self-healing composite based on simulating human bone healing mechanism, self-clearing coating inspired by lotus leaf efforts, and minimized multi-functional sensors as smart aggregates that can be mixed with concrete.

One class lecture unit focused on creativity and innovation strategies. One of the classic models of creativity, the Wallis Model of the Creative Process[26], was presented to students during the class lecture. Besides, the reference to Disney's creative cycle [51] and other strategies for creativity and innovation were given to students. The Wallis model describes four-stage process which people use to approach to problems and come up with creative solutions as followings:

- Preparation: One defines the problem, need, or desire, and gathers any information on the solution or responses that need to be encompassed, and then sets up criteria for verifying the solution's acceptability;
- Incubation: One steps back from the problem and lets his or her minds contemplate and work it through;
- Illumination: Ideas arise from the mind to provide the basis of a creative response. These ideas can be pieces of the whole or the whole itself, e.g. the entire concept or entity at once;
- Verification: One carries out activities to demonstrate whether or not what emerged in illumination satisfies the need and the criteria defined in the preparation stage.

Table 1 Suggested four phases for Problem/Project-Based Learning in re-cyclic process

Phase	Students Activities in Course Design Project and Learning Specific Topics
Plan & Design	Establish the objective of design project and learning goal for acquiring new in-depth knowledge: Students have to identified a problem needed to be solved; learn and select creativity strategies and related nanotechnology from new course modules and self-directed learning to formulate innovation; identify specific aspect of nanotechnology that would be applied for the design project; break down objective and task into several small steps with timelines for accomplishing these objectives and tasks.
Priority & Recourse	Identify priorities of learning topics and learning strategies and resources: Students needed to focus their efforts on the topic that were related to the subject they chose for the design project; identify resources to acquire the knowledge and information from lectures, course materials or reference provided by instructors, or further literature search through their own efforts; or seek the advice and suggestion from instructors or peer students.
Monitor & Conduct	Carry out the plan for learning task and design project: Students performed learning tasks through attending course lecture, self-directed learning of supplemented course materials or literature reviewing; and conducted design process through describing problems and illustrating its innovative solution through nanotechnology; monitor the progress of the learning tasks and project design and see if they meet the goals and timeline as planned.
Evaluate & Control	Evaluate learning results and final design project, and seek feedback for improvement or alternation: Students evaluate if they have achieved the objectives; seek the feedback or suggestion from themselves, instructors, or their peers on their project subject or the final innovative solution. Based on evaluation and feedbacks, students could enter the next cycle of the four phases to improve their design through acquiring additional learning; or adjust or alternate the original plan, learning tasks, or even the design subject if there is no desired progress was made. Finally, innovative design and solutions in students' design project were exchanged through final project presentations among students. Further evaluation and feedbacks can be obtained through peer comments and suggestions

Students were encouraged to make their plan and to do their own literature search for their selection of problems and development of solution or design for their projects. They were required to communicate with instructors periodically for feedbacks on the topic they selected and their working progress. The early assignment allows students to have 2-1/2 months and less time-pressure to develop their Problem/Project-Based Learning process and come up with their

own control for completing their project. A website has been developed to provide extensive resources to students, including fundamental knowledge of nanotechnology, innovation examples, creativity strategies, and reference as motioned in the above. This is the initial Pedagogical Model and was implemented for the 1st year.

The new Pedagogical Model has been evolved from the initial Pedagogical Model at the second year based on the first year implementation experience and extensive literature reviews. The new conceptual SRCP four-phase implementing feedback cycle model as shown in Fig.1 was developed to better motivate and guide students in their pursuit of creativity and innovative design through self-directed Problem/Project-Based Learning for the co-curricular design project. The SRCP model was used as a new Cognitive Instruction Model for Problem/Project-Based Learning. It was introduced to students and used to instruct and guide students during the course project assignment for new students in the same course at the second year. The four phases of SRL was further in Table 1 for guiding student project activities and included in the course project assignment.

Outcomes of the Implementation and Its Discussion

The outcomes from implementing the proposed Pedagogical Model have been empirically assessed through qualitative and quantitative evaluation as parts of the evaluation of Nanotechnology Undergraduate Education (NUE) project. The over goal of the evaluation is to measure and ensure that the project meets its objectives, and to provide feedback for further improvement for the future implementation. Adopted assessment instruments are these that can be practically administrated for engineering classroom settings. Even though they may not be rigorous, these instruments can provide certain insight into students' learning experience and progresses.

Adopted instruments include the pre- and post-test questionnaire for measuring change of students' academic dispositions through the NUE project implementation; the post-test surveys for each new course module to determine students' satisfaction level of the clarity, delivery, and content of the course module and their related learning experience; and the quality of students' projects or exams for qualifying their gain in the academic performance. In addition, students' comments and instructors' judgment on students' learning experience were used to supplement the qualitative measurement for the implementation outcomes.

Through the observation of co-curricular project implementation, it is authors' assessment that all students participated in the self-directed learning process and discussed more with instructors and their team peers for seeking feedbacks and inspirations. All students searched and reviewed literatures, and learned and presented the relevant nanotechnology for innovatively solving civil engineering problems. The students gave positive comments on their project experience and instruction approach, such as "Very helpful information and useful to use on the upcoming course project"; "Include practical applications to aid creativity"; "I think this gave the students a chance to think outside the box and allows each person to be free" "My knowledge about it is unknown, we need to brush-up on it"; "Can learn more from each other by making the presentation a group project."; and "The idea of looking materials at that scale is bound to leading to some new application."

Total forty-four student projects have been developed through co-curricular Problem/Project-Based learning during last two years. These projects presented a variety of subjects and innovative solutions beyond the scope of learning contents presented in course lectures. Several projects presented innovative solutions that were originated by students through practicing the strategies provided in the Pedagogical Model (PM), such as

- Warm in Winter and Cool in Summer: Nano-Enhanced Home through using Nanocoating for Enhancing Insulating Factor of Construction Materials;
- Smart Bridge through using smart material cables to controlling suspension bridge;
- Ideal Aggregates for Concrete through nanotechnology formation
- Multiple Function Textile Reinforced Concrete using textile made from hollow fibers containing binding agent that can provide both reinforcing and self-healing mechanism for concrete

Through the pre- and post- questionnaires, one question is particularly used to assess students' gain in their knowledge about strategies of creative thinking and creativity through their learning experience. Students were asked to give a score based on 1 to 5 scales for their knowledge assessment before and after their Problem/Project-Based learning experience. The higher score indicates more positive merit. The average score from available student participants in a class is used as a composite score for the class (see Table 2). Even though students' perception on their knowledge about strategies of creativity were varied for different classes before their Problem/Project-Based learning experience, there was noticeable gain of about 10-20% in this aspect through their experience with proposed instruction model. The lower gain for some class can be attributed to the higher perception on their knowledge on creativity from some students before the instruction implementation.

Table 2 The Pre- and Post-Test Questionnaire Results For Assessing Knowledge About Related Strategies

Implementation year	2007										2008									
Student Participants	Jackson State Univ.					Univ. of Oklahoma					Jackson State Univ.					Univ. of Houston				
Score	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Student #(pre-test)	1	2	3	3	0	2	1	6	2	1	0	3	4	2	1	1	1	6	6	2
Student #(post-test)	0	0	4	3	0	0	0	6	4	1	1	0	3	4	1	0	0	1	10	5
Pre-Ave. Score	2.89					2.92					3.10					3.44				
Post-Ave. Score	3.43					3.55					3.44					4.25				
Relative Gain	18.68%					21.56%					11.11%					23.64%				

For the post-test survey on the Course Module Of Creative Thinking And Creativity Through Problem/Project-Based Learning, students were asks to give the score based on 1 to 5 scales to five questions and provide their comments for their satisfaction level of their learning experience and quality of proposed instruction model. The genetic questionnaires are tabulated with score scales in Table 3. Table 4a to Table 4c show the average scores for this course module provided by available student participants from different classes.

In the first year implementation, results of the post-test survey revealed that lower scores of 2.63/5.0 and 2.91/5.0 were given for both interesting and practical aspects of this module by student participants from one class (see Table 4c). It suggested that these students on average did not think this module topic on creativity and creative thinking is not interesting and practical for

them, even though the students from this class has assessed 21% gain in their knowledge through their learning experience (see Table 2). The students from another class in the first year gave a higher score of 3.7/5.0 for the interesting aspect of this course module, but lower score of 3.0/5.0 for the practical aspect of the topic on creativity and creative thinking (see Table 4b).

Table 3 Genetic questionnaire on each new course module implementation

Q1. The topic of Module subject is (1) not interesting at all (2) interesting to a little extent (3) interesting (4) very interesting (5) greatly interesting	**Q2.** Do you think that the topic of Module subject is (1) not practical at all (2) practical to a little extent (3) practical (4) very practical (5) greatly practical
Q3. The course materials for Module subject are organized (1) not effectively at all (2) effectively to a little extent (3) effectively (4) very effectively (5) greatly effectively	**Q4.** The basic concept and application on Module subject are presented (1) not clearly at all (2) clearly to a little extent (3) clearly (4) very clearly (5) greatly clearly
Q5. The in-depth of the course material for the topic of Module subject is presented (1) not sufficiently at all (2) sufficiently to a little extent (3) sufficiently (4) very sufficiently (5) greatly sufficiently	**Q6.** Please give your comments or suggestions for course materials on the topic of Module subject

Table 4a The Post-Test Survey Results From Student Participants From Jackson State University 2008

Module	Module of Creativity Strategies and Problem/Project-Based Learning for Innovative Design																								
Question	Q 1					Q 2					Q3					Q 4					Q5				
Score	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Student #	1	2	1	3	2	0	0	5	3	1	0	0	7	1	0	0	2	4	3	0	0	1	2	3	3
Ave. Score	3.33					3.56					3.13					3.11					3.89				

Table 4b The Post-Test Survey Results From Student Participants From Jackson State University 2007

Module	Module of Creativity Strategies and Problem/Project-Based Learning for Innovative Design																								
Question	Q 1					Q 2					Q3					Q 4					Q5				
Score	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Student #	0	1	4	2	3	1	1	6	1	1	0	3	5	1	1	0	3	6	1	0	0	2	7	1	0
Ave. Score	3.70					3.00					3.00					2.80					2.90				

Table 4c The Post-Test Survey Results From Student Participants From The Univ. Of Oklahoma 2007

Module	Module of Creativity Strategies and Problem/Project-Based Learning for Innovative Design																								
Question	Q 1					Q 2					Q3					Q 4					Q5				
Score	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Student #	1	3	6	1	0	0	3	6	2	0	0	0	7	3	1	3	0	7	3	1	0	0	10	1	0
Ave. Score	2.64					2.91					3.45					2.93					3.09				

Further examination of the post-test survey data from the first class (see Table 4c) revealed that 50% of students rated this topic "interesting" and 8.3% of students rated it "very interesting", while 50% of students rated the topic "practical" and 16.6% of students thought it "very

practical". This indicates the majority of students think this topic on creativity and creative thinking is both interesting and practical to them. However, 8.3% of students rated this topic as "not interesting all"; 24.9% of students rated it "interesting to a little extent" and "practical to a little extent". It is the authors' assessment that these students who rated the topic with lower score may be not interested at research or invention, and may also not realize the strategies and practice for creativity and creative thinking could benefit their routine learning and problem-solving. Thus, the need for further improving this module content and instruction had been identified in the first year implementation.

The efforts for improving the above course module had focused on enhancing students' perception on creativity and emphasizing the linkage of creativity strategies with routine self-directed learning and problem-solving skills. As a result, the new proposed Cognitive Instructional Model (CIM) of Self-Regulated Learning and Creativity (SRLC) Process has been developed and integrated into this course module for enhancing Pedagogical Model (PM) as mentioned in the proceeding. The improved Pedagogical Model has been implemented for the new students in the same course at the second year.

With such improvement, the score on the practical aspect of this module topic by students from one class at the second year has been improved up to 3.56/5.0 (see Table 4a). These students' satisfaction level of the clarity, delivery, and content of this module (see Table 4a) was also enhanced in comparison with these in the first year implementation (see Table 4b and 4c). Even though the data from another class at the University of Houston are not available yet, students from the University of Houston have perceived a higher gain of 23.64% in their knowledge on creativity and creative thinking strategies (see Table 3).

The implementation of the proposed Pedagogical Model suggested that an early-assigned open-end course project, which contains appropriate challenges that can match students' capability, requires some innovations, and allows students to have autonomy in selecting their learning subject, can be a suitable way to involve students in self-directed learning and creativity process and promote use of cognitive skills and creativity strategies. Within the Pedagogical Model, the proposed Cognitive Instructional Model (CIM) of Self-Regulated Learning and Creativity (SRLC) Process could facilitate students to perceive the importance of pursuing creativity for their routine learning and problem-solving, and to motivate their efforts for self-directed Problem/Project-Based Learning process. In addition, final project presentation and the team work provide an opportunity for intellectual exchange among students not only from civil engineering majors, but also from technology and mechanical engineering majors, and to help development of an inventory of innovative ideas for these students.

Further Improvement and Discussion

Since the proposed Pedagogical Model (PM) was initiated as parts of Nanotechnology Undergraduate Education project, the instruction and evaluation mainly focused on the impact of nanotechnology education on students' vision for future civil engineering, gain in fundamental knowledge of nanotechnology, and inspiration from nanotechnology innovation. They may not be very rigorous for promotion and assessment of creativity and self-regulated learning skills. As authors have gained experience through the proposed Pedagogical Model implementation and

expanded their knowledge from reviewing Cognitive Science literatures, some improvements for the proposed <u>Pedagogical Model</u> are identified and discussed for the future instruction and assessment of the Problem/Project-Based Learning with the proposed <u>Cognitive Instructional Model</u> of Self-Regulated Learning and Creativity (SRLC) Process.

The current course project assignment only requires the innovative solutions or the originality in creativity, and has not emphasized on other two major aspects of creativity: Idea Fluency, i.e., how many ideas have been generated; and Flexibility, i.e. how many different approaches have been considered. The grading criterion for the course project can be improved to cover these three aspects of creativity. Students' reflection during their self-directed Problem/Project-Based Learning is important, but was not visible to themselves or their peers. The future instruction needs to be strengthened in promoting students' reflection on their successful decision and utilization of different strategies for their learning and problem-solving, as well as their reflection how to extend these strategies into other contexts. The reflection process should be presented as part of their final project presentation. More weight in the grading criteria for the students' projects can be placed on the process in this regard to promote reflection.

The current data collections for assessing the outcomes of the proposed <u>Pedagogical Model</u> are subjective to opinions of students and instructors. They are not very rigorous for addressing students' gain in their creativity and self-regulated learning skills. The further efforts have been planned to develop rigorous instruments suitable for engineering education setting through adapting available instruments developed from Cognitive Science and Educational Psychology. The candidates of these instruments includes standardized creativity test instrument, Torrance Test of Creative Thinking (TTCT)[18], and SRL assessment instruments, Strategies for Learning Questionnaire (MSLQ) [52] and Self-Regulated Learning Inventory (SRLI) [53,54]. The original these instruments contain different categories of complete creativity and SRL components, e.g. student motivation, cognitive strategy use, and metacognitive strategy use, management of efforts, and environmental control/utilization. However, they were designed and tested for general learning and contain many items. TTCT is particularly administrated by testing agents and graded by experts. Thus, adaption of these instruments for engineering education setting deserves further efforts and could improve the assessment of important attributes of creativity and self-regulated learning for engineering students.

Summary and Conclusion

Research from Cognitive Science supports that creativity and self-regulated learning is correlated metacognitive processes. Metoacognition training on creativity and self-regulated learning needs acquiring not only knowledge and strategies for creativity and self-regulated learning, but also control experience for creativity and self-regulated learning over a specific cognitive tasks. Motivation is critical for engaging students in these metoacognition training and can be enhanced if the components of motivation are clearly addressed for students. If applied properly, these metacognition trainings could effectively enhance students' performance and self-confidence in their creativity and self-regulated learning, which lead to enhanced self-efficacy (or confidence) and motivation for pursuing greatness and well-being through self-actualization, and in turn help maintain the efforts for self-regulated creativity and learning. The available literatures suggest there are synergy and interaction among creativity, self-directed learning, and motivation.

The proposed <u>Pedagogical Model</u> and <u>Cognitive Instructional Model</u> of Self-Regulated Learning and Creativity Process (SRLC) are built on engineering education practice and theoretical framework from Cognitive Science. The proposed <u>Cognitive Instructional Model</u> of Self-Regulated Learning and Creativity Process (SRLC) involves self-monitoring and self-correction of three aspects of creativity and learning: i.e., motivation, metacognition, and strategic action. The proposed <u>Pedagogical Model</u> integrates Problem/Project-Based Learning and proposed <u>Cognitive Instructional Model</u> into a co-curricular design project. It could support creativity and self-regulated learning and help result in positive attitude and skills.

The implementation outcomes suggest that proposed <u>Pedagogical Model</u> could be suitable to involve students in active self-directed learning process and promote acquiring and using cognitive strategies. Further improvement for the proposed Pedagogical Model has been identified. It includes emphasizing all three aspects of creativity, i.e. originality, idea fluency and flexibility in students' project requirement; promoting students to reflect on their creativity and learning process, and extension of their successful experience to other context; making such reflection visible to themselves and their peers through students' project presentation; and developing instruments suitable for engineering education settings for more rigorously measuring students' gain in creativity and self-regulated learning skills.

Acknowledgements

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