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論 文 内 容 の 要 旨

1. Need for this Work: The world depends on engineers to creatively design items, processes, and services to satisfy human needs. To meet these demands, engineers need to be more creative because of the complexity of modern design.

2. Thesis Objectives: To enhance creative engineering design (add creativity to the components of a typical design process) and to promote creative thinking in engineering students.

3. Meeting the Thesis Objectives: Barry developed five creative teaching models (along with complementary materials including published books) to support the required components of a typical engineering design process. The models have been successfully used with engineering students in the US and Japan, and received a national Award of Excellence from the American Chemical Society in 2007.

4. Initial Collaboration with Japan: At a time when Japan was interested in creativity, Barry presented a creative paper at an online conference in 2001. This paper caught the attention of her current collaborator in Japan. This meeting in cyberspace initiated their collaboration.

5. Five Creative Teaching Models: These models promote higher level thinking and are to be incorporated into existing college engineering courses. While using these models, instructors need to be open-minded and more like facilitators.

A. Multisensory Teaching Model: Engineering students are encouraged to work on their own. Lessons incorporate the use of the senses (smelling, touching, etc.) and combine music, visual aids, and engineering activities (including reverse engineering). This model was successfully used with several hundred engineering students in the US and Japan. The model supports parts of a typical **Engineering Design Process**. The senses are used to **Evaluate the Alternatives**. Seeing determines the appearance quality and touching determines the texture quality, etc. This model prepares engineering students to **Communicate the Selected Design** by describing the visual appearance, the texture, the odor, etc. of the designed item.

B. Science Fair Project Teaching Model: Students have an opportunity to select an interesting problem for their engineering design project. They are encouraged to work on their own. Students perform mental exercises in collecting, analyzing, etc. data and in preparing oral and written reports and displays, etc. for their design projects. This model includes published books written in Japanese and English. The model supports parts of a typical **Engineering Design Process**. Students have an opportunity to **Identify the Problem** (one they would like to solve). They **Evaluate the Alternatives** using special instruments available in a laboratory setting. The engineering students are also prepared to **Communicate the Selected Design** by using various forms of communication.

C. Reading and Solving a Mystery Teaching Model: This model encourages engineering students to act on their own (like detectives) to solve a crime or problem by collecting evidence or data. It includes published books written in Japanese and English, many writing and verbal exercises, reverse thinking, and role playing. The model supports parts of a typical **Engineering Design Process**. It provides engineering students with many experiences in **Collecting Data to Solve the Problem**. This approach (which includes many exercises in oral and written communication) prepares students to **Communicate the Selected Design.**

D. Space –Related / Space Exploration Teaching Model: The engineering students are usually given a problem to solve. They are of diverse backgrounds (to increase the flow of ideas) and work in small groups to discuss the problem, generate possible solutions, evaluate them, build prototype models, etc. Also they prepare diagrams, etc. to express their ideas. Engineering students in the US and Japan used this model to successfully carry out the Lunar Greenhouse Design Challenge. This model supports parts of a typical **Engineering Design Process.** For the Lunar Greenhouse Design project, engineering students **Identified Design Requirements** (the design and shape of the special greenhouse and systems to sustain plant life). They also **Identified Design Limits** (such as materials and resources available). Students **Generated Possible Solutions to the Problem** as a result of brainstorming sessions and **Communicated the Selected Design** through written statements, diagrams, prototype models, etc.

E. E-Learning Teaching Model: This model uses software and electronic media. It should be used for problem-based and creative engineering design activities that are difficult or impossible for engineering students to carry out in real life. Students work in small groups to discuss the problem, generate possible solutions, etc. Engineering students in the US and Japan successfully used this model in Metaverse to design and build the typical house of the global warming period. This model supports parts of a typical **Engineering Design Process.** Engineering students **Generate Possible Solutions to the Problem** by holding brainstorming sessions and by using computers. They are able to **Evaluate the Alternatives** by using computer-based models and to **Select the Best Approach** using computer-aided design, etc. This model is important for **Communicating the Selected Design,** especially if the designed item is to be made by a machine or robot because the final specification or design might be stored on a disk or in computer software that controls the machine's or robot's actions. All of the creative teaching models can be used to **Implement the Final Design.** However, the E-Learning Teaching Model is recommended for special items made by machines and robots.

6. CONCLUSIONS

A. Expected Results of Using the Creative Teaching Models: It is expected that the models will be incorporated into engineering classes and curriculums at various colleges. As a result, it is also expected that engineering students and new engineers will have enhanced creative thinking and enhanced creative engineering design skills, which should improve their ability to solve the challenging problems of our ever changing world. An increased enrollment in engineering education is also expected. (Students should be excited about joining engineering classes that provide enjoyable design projects and activities where they have opportunities to be creative and to solve problems of interest to them. Companies such as 3M actually pay and encourage their engineers to do this.)

B. Some Important Results of Barry's Research

1. Many of Barry's teaching approaches are being used to teach engineering classes at Suzuka National College of Technology, Japan. In particular, two of the creative teaching models (the Science Fair Project Teaching Approach and the Reading and Solving a Mystery Teaching Approach) have been incorporated into the Materials Science and Engineering Department's formal curriculum at Suzuka National College of Technology. As a result of using these creative teaching approaches, the engineering students are excited and highly motivated. Also since these models add creativity to the components of a typical engineering design process, the students' engineering design capability should also be enhanced.

2. Student participants developed communication skills (which are essential to all aspects of engineering design) and successfully defined problems to solve and effectively described their possible solutions for many design problems. The engineering students performed mental exercises in higher level thinking (synthesis: creating new ideas, etc. and evaluation levels of Bloom's Taxonomy). They used Barry's creative mystery books to carry out many of these activities.

3. The engineering students were encouraged to think "outside of the box." They had many creative ideas (as compared to the students told to think inside of the box, which limits creativity). For the Lunar Greenhouse Challenge, each US student had multiple ideas (possible solutions) for the plant growth chamber. Also the engineering students in the US and Japan had a number of creative ideas for the Problem-Based Learning Project in Metaverse, where they were asked to design and build the typical house of the global warming era. Their ideas (resulting from brainstorming sessions in Second Life) were recorded by special equipment during chatting sessions.

4. Overall the engineering students in the US and Japan were highly motivated as a result of using the teaching models. Student survey results support this statement, especially those of several hundred students (in the US and Japan) who participated in the Multisensory Teaching Program.

論文審査の結果の要旨

本論文では、創造的エンジニアリング設計ならびに創造性開発に対する5つの新たな手法、すなわち[1]五感を活用する手法、[2]サイエンスフェア・プロジェクトによる創造性開発、[3]ミステリーを利用した問題理解と解決手法、[4]宇宙探査プロジェクトを通じた創造性開発、[5]グループ討議型e-learningシステムの開発が提案され、それぞれの手法がエンジニアに必要とされるチームで問題を解決する能力開発や、工学における創造的設計能力、さらにはコミュニケーション能力等の向上に有効であることが示されている。その成果を要約すると次の通りである。

(1) 本研究で提案された創造性開発に対する5つの手法は、いずれも次に示す学習過程をたどって次第に創造力を高めるように設計されている。すなわち、知識(Knowledge)→理解(Comprehension)→応用(Application)→分析(Analysis)→統合(Synthesis)→評価(Evaluation)の過程である。この学習過程は工学における設計プロセスにおける知識操作モデルとよばれる過程にきわめてよく対応しているために、本研究で提案された5つの手法を実践することにより、エンジニアリング設計能力が涵養されることを明らかにしている。

(2) 聴覚に訴える音楽など、五感を使った化学分野における創造性開発手法（ケミカルセンセーション）の理論が提案され、その実践による効果が述べられており、感性を活用することの有用性とその具体的方策を見出している。

(3) サイエンスフェア・プロジェクトについて、工学に必要な問題解決モデルに従って学習を進めるプログラムの設

定とその実践が有用であることを、その具体例と参加者に対する事後調査等を通じて明らかにしている。

(4) ミステリーを利用した創造性開発を新たに提案し、その理論と実践手法ならびにその効果を明らかにしている。特にこの手法の適用によって、当該学生・研究者は問題解決の手順をより容易に理解し、同時に上記の学習過程を低次から高次へと進めることができ、創造的エンジニアデザイン能力の涵養に資することを明らかにしている。

(5) 創造性開発の具体例として、宇宙探索アプローチについての理論と実践およびその成果について、日米の学生をそれぞれ対象とした実践例とその効果に対する比較検討が詳細になされている。また、チームを組んで問題解決を行うことを想定したe-learningの理論と実践結果について、日米の学生がそれぞれ３次元仮想空間でチームを組んで問題解決を図った実践例が詳細に検討されている。これらの創造性開発手法を通じて、本来個人の能力開発のために構築されてきたe-learningがチームによる問題解決を図る手段としても有効であることが明確に示されている。さらに、これらのすべての成果が、国境を超えて日米双方において有効に適用できることを明らかにしている。

(6) 本研究で試みられた手法とその成果は、日本のみならず、米国や欧米諸国においても新規性の高いものであり、特に米国連邦政府が力を入れている青少年全般あるいは理科教育の教師全般への科学教育であるところのSTEM(Science, Technology, Engineering and Mathemtics)教育にも役立つものであることが明確に述べられている。

以上のように、本論文は創造的エンジニアリングデザインに対して５つの手法を提案し，我が国の工学教育・創造性開発への適用の可能性を検証したものである。本論文で提案された創造性開発手法は工学における問題解決モデルならびに実践手法として有効な手段であり、また、エンジニアリングデザイン能力の涵養にもきわめて有用であることが日米において協力関係にある教育現場での実践例を通じて明らかにされている。得られた成果は国際共同研究を行う際に必要となる研究計画・問題解決のための設計手順を構築する際にも極めて有用であり、生産科学の発展に大いに寄与するものと評価できる。よって本論文は博士論文として価値あるものと認める。