Paper ID #41400

Board 88: Visual Representation Based Creative Problem Solving (CPS) for Microelectronic Course

Prof. Gon Namkoong, Old Dominion University

Gon Namkoong, Ph.D. Professor ECE department Old Dominion University Applied Research Center 12050 Jefferson Avenue Suite 717 Newport News, VA 23606 Tel: 757.269.5349 email:gnamkoon@odu.edu

TIAN LUO, Old Dominion University

Visual Representation Based Creative Problem Solving (CPS) for Microelectronic Course

Prof. Gon Namkoong, Old Dominion University
Gon Namkoong, Ph.D. Associate professor ECE department Old Dominion University Applied Research Center 12050 Jefferson Avenue Suite 717 Newport News, VA 23606 Tel: 757.269.5349 email:gnamkoon@odu.edu

Prof. Tian Luo, Old Dominion University
Associate Professor, Department of STEM Education & Professional Studies, 4301 Hampton Boulevard Suite #4106, Norfolk, VA 23529

Introduction

The complexity and diversity of 21st century technologies force engineering schools to reconsider the role of future engineering students as a leading workforce and the education needed for them to fulfill their role. This is because contemporary problems are not well defined and have multiple possible causes that are unlikely to be solved by traditional means. Schools and universities still prioritize a convergent type of thinking where the students use rules and structured processes to come to the one "right" solution. While in many cases, this strategy is useful and necessary, real life is complex, dynamic, and imprecise enough that it is unrealistic to think that problems have only one solution. Therefore, students need to learn how to use true creative thinking. Realizing this contemporary demand, the Accreditation Board for Engineering and Technology (ABET) 2018-2019 criteria[1] shifted the emphasis of engineering curriculum by identifying creative problem-solving skill as a vital component for improving the future of engineering and engineering education. Particularly, ABET 2000 Criteria[1] requires visualization, cognitive model, communication, teamwork and creative problem solving.

In response to these trends, more engineering courses are being designed to incorporate more innovative, creative problem-solving skills[2,3,4,5]. Some examples include field trips or mini competitions as a creative model to encourage creativity[6]. In addition, problem-based learning and critical thinking skills in the context of real-world problems have been integrated into engineering education to facilitate students' divergent thinking during the idea generation phase[7]. Among them, the most common instructional approach in engineering education is open-ended design projects, where the target product is not defined in order to allow creative opportunities[3,5]. One argument in favor of open-ended design projects is that students reflect on their own creative processes as they work through a project and thereby see ways to improve their creativity[8]. However, the infusion of open-ended design activities in the engineering curriculum has been limited to "synthesis" exercises using known methodologies or exercises[9]. In this situation, students mostly follow well-proven design techniques that were covered in the textbooks or lectures rather than being challenged to think through a new process or create a unique solution. To have more and better distributed opportunities to develop their creative problem-solving skills as an integral part of their four-year college education, various pilot studies have been conducted to reform the learning environment within regular courses to affect the students' creative problem-solving skills[10,11] without solely relying on open-ended design projects. However, there is a big question begging how students can be creatively motivated and practice and exercise creative inspiration from outside the box within regular courses. The ideas for creative problem solving (CPS) began in 1963 when Osborn[12] integrated the creative skills process in solving problems. Unfortunately, literature reviews indicate that very little research has been done that supports students' generic skills and knowledge construction through CPS, there is still a lack of instructional materials in the engineering context, and a lack of instructor knowledge of how to support students in developing creative problem-solving skills.

Visual representation based creative problem-solving

Creative problem-solving (CPS) is a cognitive process in finding ideas and alternatives to overcome any barriers in original ways when an existing process fails. Particularly, CPS involves balanced thinking processes, namely convergent (generating one correct solution to posed problems) and divergent thinking (generating multiple solutions to posed problems). Current engineering education settings still prioritize convergent strategies where students use rules, and structured processes to come to the one "right" solution. While, in many cases, this strategy is necessary, real life is complex and imprecise enough that it is unrealistic to think that problems have only one solution. Given that divergent (or creative) thinking is a high priority for our future engineers, today's engineering students should be well trained to come up with ideas culturally and tackle problems in creative ways. In this regard, the critical challenge lies in how to effectively infuse CPS into the engineering curriculum without compromising the existing standards and how to overcome barriers that impede the integration of CPS in engineering education.

Typically, CPS model involves five stages, namely 1) facts-finding, 2) problem-finding, 3) idea-finding, 4) solution-finding and 5) acceptance-finding[13,14]. At the stage of "Facts/Problem Finding", students will identify problem or challenge and start to collect information and develop a clear understand of it. The "Idea Finding" phase is to generate ideas to answer the challenge questions. The "Solution/ Acceptance Finding" phase shifts from ideas to solutions in which convergent thinking can be used to narrow ideas down to the most suitable solution. A unique feature is that each step first involves a divergent thinking phase in which one generates lots of ideas (facts, problem definitions, ideas, evaluation criteria, implementation strategies), and then a convergent phase in which only the most promising ideas are selected for further exploration. The challenge is how to assist our engineering students in seamlessly exercising a series of creative problem-solving stages. In this case, integrating visual literacy into CPS model will serve as a bridge between the CPS stages, facilitating the imaginative, innovative and creative thinking aspects. This hypothesis is based on the fact that visual literacy can promote students' synectic exercises as part of spatial reasoning and manipulation experience. Indeed, Paul Messaris argued that "by acquiring visual literacy, people enrich their repertoires of cognitive skills and gain access to powerful new tools of creative thought." Pun et al also described that "problem solving in art involves divergent thinking and multidisciplinary knowledge which in turn nurture creativity". Furthermore, visual literacy involves awareness of and reflection on what students experience when they draw or view images, videos and other forms of multimedia.

As a creative synectic exercise we propose 'visual representation'[15,16] that takes many different forms like sketches, models, prototypes, outlines, concept maps, tables, wireframes, etc. In this project, visual representation is defined as the rough or mockup drawing to primarily communicate design ideas and to visually articulate design ideas. Currently, visual representation can be used as a valued practice for capturing or translating desired information into visual forms in a speedy but creative way. That said, many visual representations can be initiated to interpret needs and problems and visually presents their conceptualization with hand-drawn representations. At a first step, it purely displays 'the idea' and more ideas can then be refined and iterated. Also, multiple representations can be performed to reach a single idea. Unsuitable ideas can simply be crossed out and newer iterations can be drawn alongside the discarded drawings. In this way, the practice of visual representations will stimulate creative thinking skills [17] by paving new ways for idea generation in an individual generation-reflection-interpretation cycle [18].

Similarly, students face many engineering problems that require first grasping the underlying principles of the problems, reflecting and interpreting them from their own experiences and perspectives, and then transforming them into practical solutions. While confronting engineering problems, students need to nurture creative problem-solving skills in daily classroom settings where resources such as lectures, laboratories, projects and assignments must all be aligned with the creative learning cycle. In this regard, we believe that the potential and flexibility of visual representation practices as part of a CPS are huge and can be readily infused into daily and diverse classroom settings. Note that visual representation looks similar to sketching in that drawing practices share some commonalities. However, visual representation integrated CPS can bring multifaceted impacts where students may experience creative synectic exercises and momentums including:

- **Critical reflection/interrogation/self-explanation of the problem:** In order to transform engineering problems into analogous visual forms, students must fully understand the underlying concepts of the problem. This implies that the students identify the problem, reflect on what they have already learned, and then undertake active inquiry and deep research on topics and subjects. This will facilitate "facts-finding and problem finding" stage.
- **Brainstorming:** Once the underlying concept is fully understood, it triggers an imaginative and divergent thinking to make visual representations, allowing students to see subjects from different perspectives. This will facilitate "idea-finding" stage.
- **Visualization and Creation:** Students start to work on visual representations based on previous experiences and ideas to visualize the concept of the subjects. In this process, students will try to express them in different ways that visually depict information on the topic. While visual representation is being iterated to form the final design, the students' reflective learning will also be iterated and integrated. This will facilitate "solution-finding" stage.
- **Contextualization:** Visual representation includes a reflection-driven short essay and/or scenario that describes the link between the visual representation concept and the underlying principle of the subject. This will facilitate "acceptance-finding" stage.

Implementation of visual representation integrated creative learning modules for microelectronic class

Creative learning modules incorporating visual representations for a microelectronics class were developed and implemented. In this case, the learning module consists of lectures and project-based hands-on experiments as a means to foster students' creativity and deeper understanding of the subject matter. Students worked on a team project to build a solar charge controller infused with microelectronic topics such as pn diodes, bipolar junction transistors, metal oxide semiconductor field effect transistors, current/voltage sensing, and pulse width modulation techniques. Mastering these topics can be challenging, so visual representations are designed to facilitate student learning including;

- the principle of pn diode and related circuits that enable the Arduino microcontroller to operate PN diode-based light emitting diodes (LEDs)
- the operational principles of bipolar junction transistor (BJT) and its circuits that enable the Arduino microcontroller to control transistors.
- characteristics of metal oxide semiconductor field effect transistor (MOSFET) and its circuits to control power.
- voltage divider circuits to sense voltage reading from solar panel.

- photocurrent sensing circuits using ACS 712 sensor to read current from solar panel.
- building pulse width modulation circuit using Arduino to control charging of battery.
- building solar charger controller using PN diode, LEDs, BJT, MOSFET, current/voltage sensor, and pulse width modulation.

Theory of MOSFET (lecture example)
The purpose of the lecture is to provide a basic understanding of the operating principles of MOSFETs and to improve student capability for MOSFET circuit design. The lesson begins with the physical structure of a MOSFET, which has three terminals: gate, source, and drain (see below for pinout). N-channel MOSFETs are voltage-controlled devices. Figure 1 shows an example showing the principle of metal oxide field effect transistors (MOSFET) that is composed of source, gate and drain. MOSFET is widely used for many modern devices such as switch mode power supplies, drivers and so on. The understanding of operational principle lies in a qualitative understanding of how MOSFET operates, which contains numerous abstract formulas and principles. Visual representation was exercised for students to master the underlying principle of MOSFET diode physics. In this case, visual representation method has been applied where students visualize the principle of MOSFET, shown in Figure 1. Student clearly show the role of source, gate and drain where the MOSFET current flow is clearly visualized.

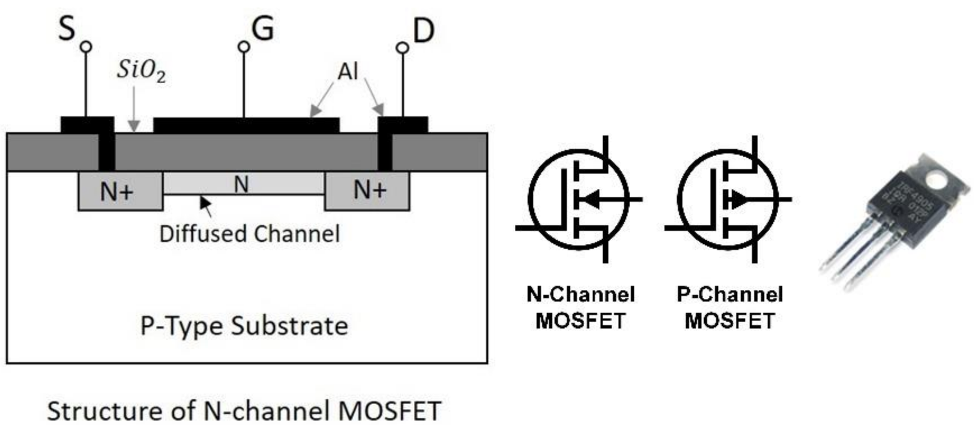


Figure 1. Structure of MOSFET and symbols

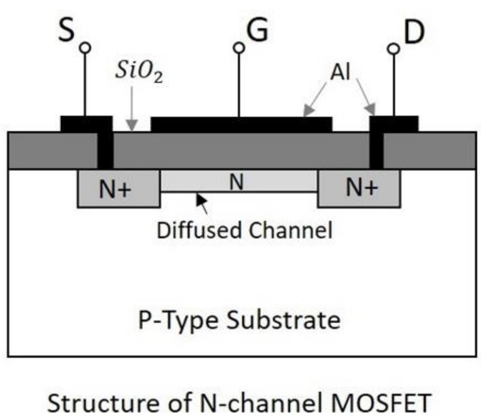
Visual representation activity
Students were challenged to express the principles of the topic. The purpose of these activities is to first identify the fundamental principles of the problem, reflect and interpret them from one's own experience and perspective, and then convert them into practical solutions. Particularly, visual representation was designed to integrate the key activities including i) identifying the problem, ii) Brainstorming, iii) Visualization and Contextualization.

Guidance of visual representation

a) Students can draw by hand or use free design or drawing tools available on their computers (Word, PowerPoint, Inkscape, GIMP, etc.) or phones (Adobe Illustrator Drawing, Sketch, PaperDraw, etc.).

b) Because some students are not good at drawing, students are permitted to use digital photos, drawings, or free images related to engineering problems to create solutions and/or explanations with annotations and prompts.
c) Once students create visual representation, contextualization using reflective essays or narrations were practiced, which describe the link between the visual representation concepts and the underlying principle of the subject. This step allows students to choose the best solution from a variety of ideas, as well as provide opportunities to justify their visual representations of engineering problems.

Examples of student visual representation
Problem statement: Students explore the relationship between applied voltages and operating modes of the MOSFET and to design a MOSFET amplifier that operates in the appropriate operational mode. The MOSFET is a voltage-controlled field effect transistor that is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide. MOSFETs are three terminal devices with a Gate, Drain and Source. Typically, students are challenged to express the principle of operating mode of MOSFET at applied voltages at Gate, Drain and Source, and channel configurations (P-channel or N-channel, or depletion or enhancement).



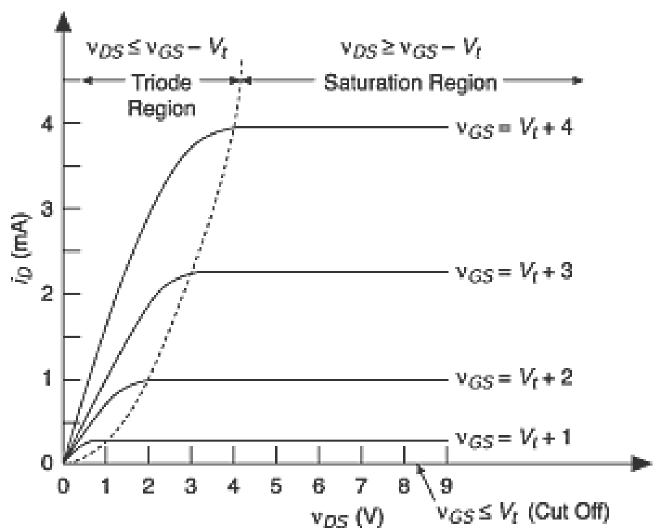
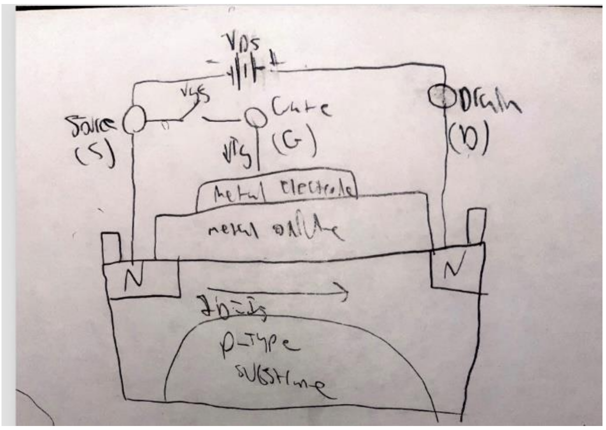


Figure 2. Operation of MOSFETs.

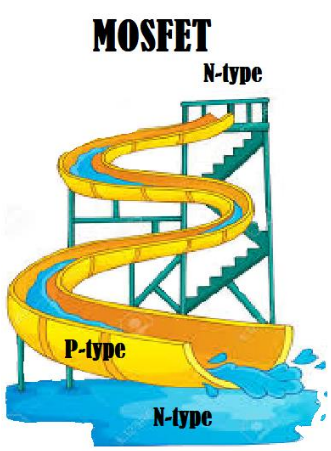
Visual representation
Provide visual representation to explain the working principle of MOSFET and describe the underlying stories.

Example 1.



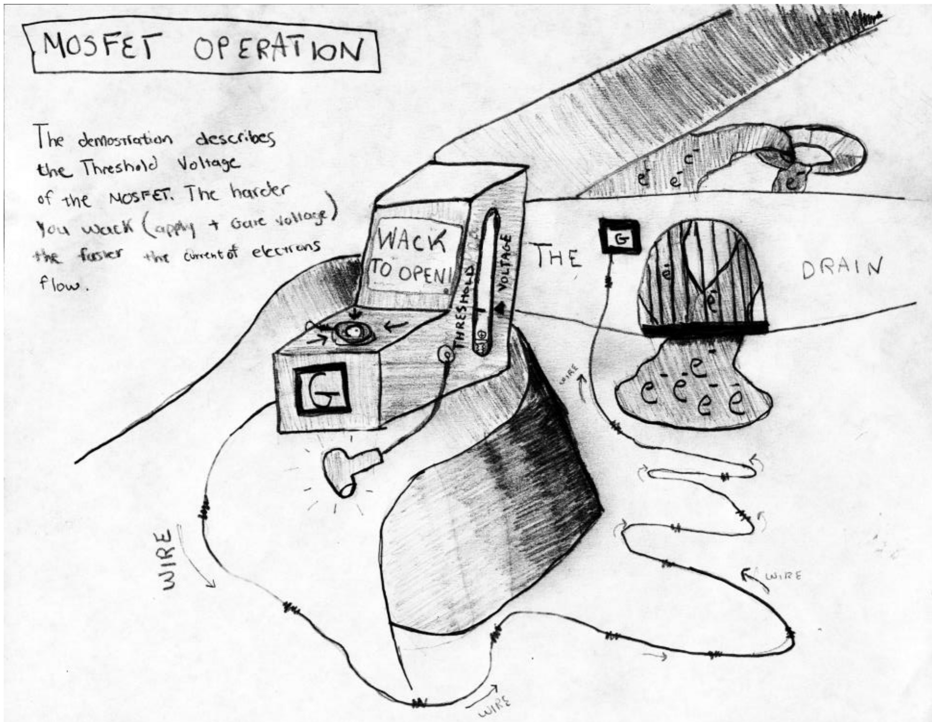
Student essay: There is a switch for the VGS that represents the Voltage turn for the gate. ID = IS and they flow from Source to Drain while Ig flows into the metal electrode. ID and Is relationship is that they equal each other as you saw in the In-lab section and Ig depends on the switch.

Example 2.

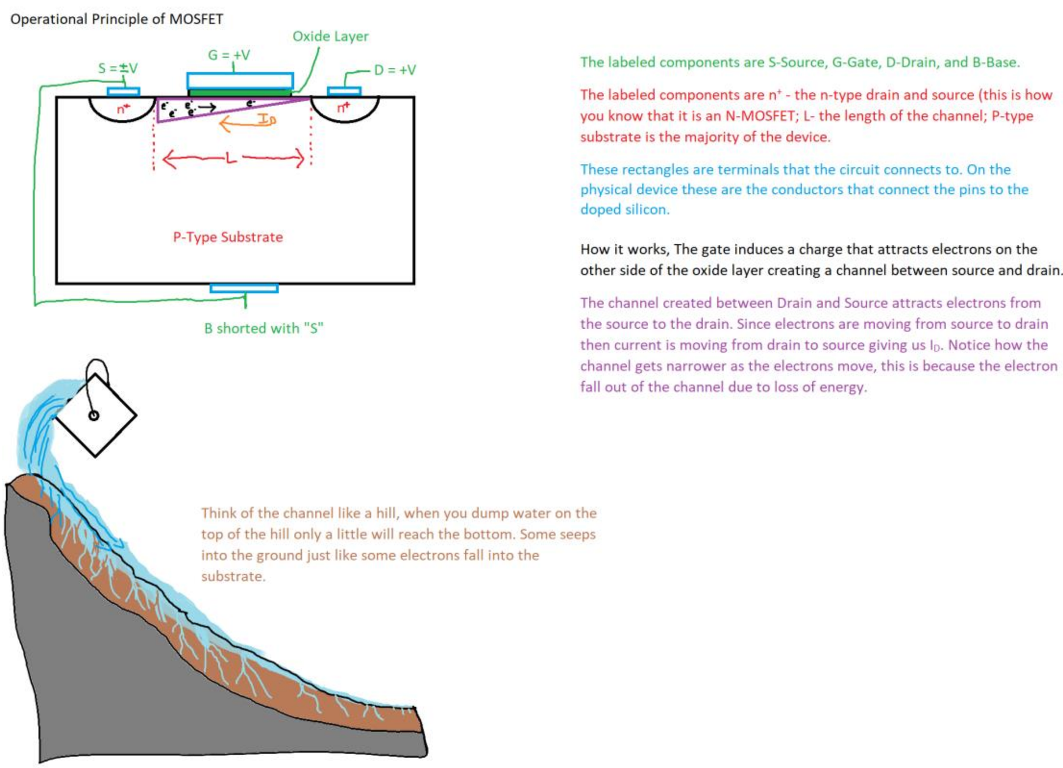


Student essay: Operational principle of MOSFET acts like the waterslide, with the water being electrons and flowing from n-type to n-type through the p-type because of a difference in potential.

Example 3.



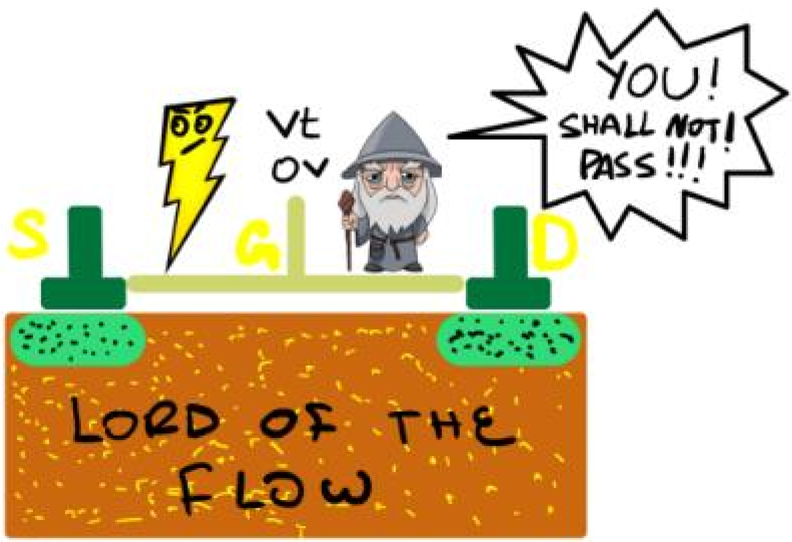
Example 4.



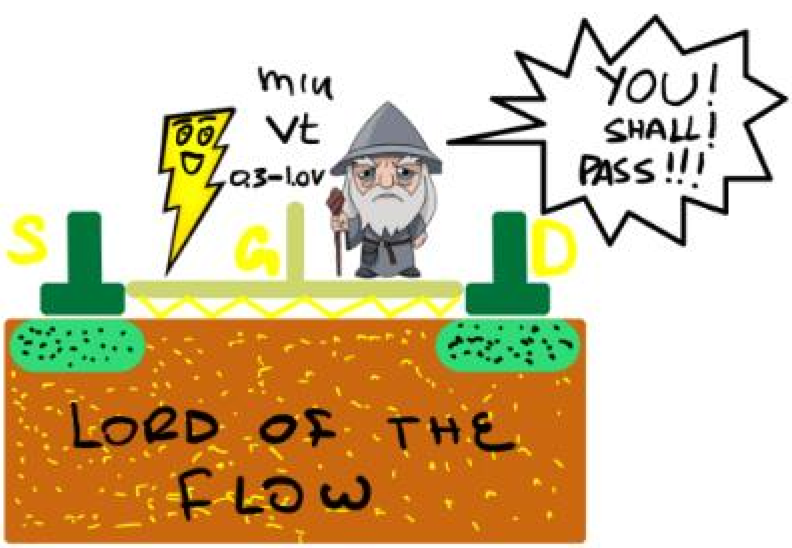
Example 5.

MOSFET:

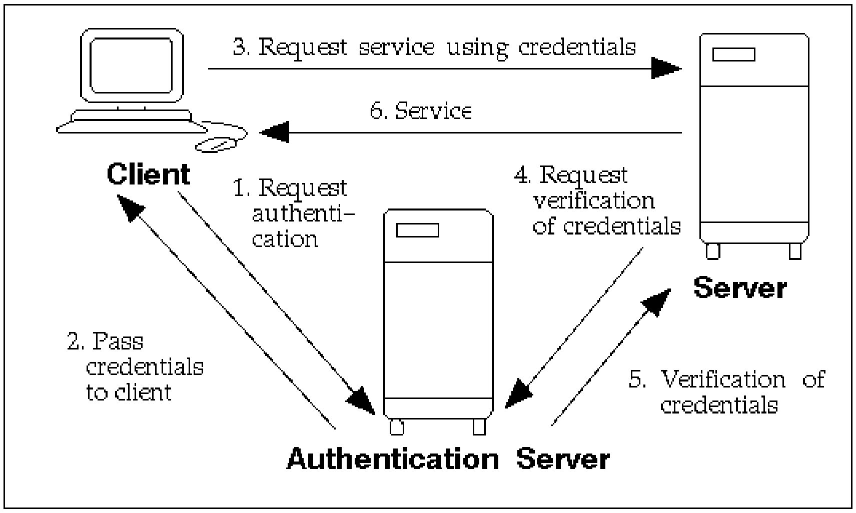
The MOSFET'S operational principle, is mainly acting as a switch. The MOSFET controls the electrical current between one contact known as the Source, and an other known as the drain, by applying voltage at a third one known as the Gate.



By modifying the voltage applied to the Gate(between 0 and above 0.3-1 V), a
a conducting channel can be made to flow or not flow, turning the device on or off.

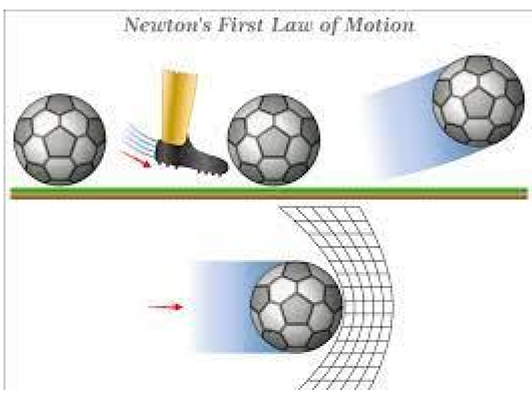


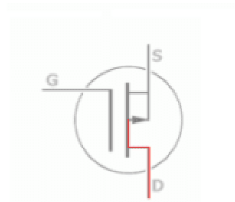
Example 6.



Student essay: The MOSFET gate acts like an authentication server in the middle of traffic flow. The source of information (the client) cannot send traffic to the drain of information (the server) if proper conditions has not been set by the gate (authentication server). Also, if the interface becomes saturated the packets sent to the server will be dropped, which means that only a certain level of traffic flow is allowed through.

Example 7.





P-Channel

Student essay: This is similar to the gate voltage because for a gate voltage to turn on a MOSFET the voltage needed to reach a certain volt to turn it on then it will stay on. Newton's first law says once an object is in motion it will stay in motion so once a object gets to a certain point it will keep going the same way a ball does until it get stopped (or till the voltage is turned below a certain threshold)

Student surveys from pilot study

“It gives us the opportunity to do something other than just solving circuits. It also encourages us to do more research on the subject and learn more about the process itself rather than just memorizing the equations that are given. It also lets us do something creative rather than just solving problems. I would like to be able to do the visual representation and essays again in the future, if given the opportunity."

"The visual representation was somewhat helpful to understand MOSFET. Although it was difficult in the beginning, trying to figure out how to represent the different concepts of MOSFETs in a creative way was helpful. Through my thought process, it allowed me to relate the concepts to things that are not completely technical, which makes it easier to remember."

"I think that the visual representation essay project that was presented today in class was very creative and thought provoking. This activity was a good way to visualize MOSFET after studying its characteristics and operation. I believe that such projects help students to better understand the material and memorize the key characteristics and models of a given device. It was a very beneficial experience."

"I believe the visual representation and essay approach was a great way to incorporate the knowledge we have gained during the semester into a fun and helpful assignment. It also gave me the opportunity to look deeper into the operation of the components we are studying and express the operation of the component in a way that even a novice to electronics could understand. The assignment also caused a bit of a buzz around the students and many of us were eager to share our essays with one another. Great idea!"

"I found the visual representation to be fun and a good way to better understand how MOSFET's work. It was a nice change to be able to apply some artistic creativity to engineering concepts, something that we rarely get the chance to do. I feel that the engineering program sometimes overlooks creativity as one of the pillars of engineering. Personally, I found that I got the most out of this project from creating my own photo essay, not necessarily from seeing everyone else's. In order to simplify the concept of a MOSFET so that I could create a visualization, I actually had to do a bit of research and I felt that I had a much better understanding of how a MOSFET works after I completed my photo essay. I really liked this assignment and I think it's something that you should continue with in future classes."

"I liked the idea of the visual representation project a lot, I learned a lot more about the use of MOSFET's by creating the drawings. It was hard to get an idea and learn from the other drawings in class because of the time constraint. I loved how creative other students were and I am probably going to be doing this on my own for other classes. You truly understand a topic when you can explain it and I like to refer back to my notes whenever I can so this will definitely help with studying in the future."

The overwhelming majority of the comments received highlighted visual representation as a new and authentic experience in engineering education. As seen in students' visual representation, we have observed students' CPS in translating abstract concepts into tangible ideas. There were many common comments on visual representation experiences from the student surveys that are summarized below:

- The visual representation approach seems to prompt students to actively participate in reading textbooks, lecture notes and a variety of sources such as several informational videos on specific subjects.

- Students regard visual representation practices as creative and thought-provoking processes that allow them to better understand the subject, rather than memorize the equations and key characteristics.
- Students seem to appreciate the visual representation approach, which allows them to have a deeper understanding of the subject and a long-lasting knowledge.
- Students perceive visual representation reflective practice as a pleasant and informative experience.
- It appears that students got benefits from visual representation reflective practices and want to apply the approach to other classes.

Student performance

An initial assessment was conducted on a control group and treatment group with visual representation. The averages of quiz, lab reports, and final presentation of the control group without visual representation components were 79, 83 and 76.8. In contrast, the averages of quiz, lab reports, and final presentation of the treatment group with visual representation components were 89.5, 86 and 91. Initial evaluations showed some improvement. However, the sample size was 14, so further evaluation using a larger sample size is needed and will be reported elsewhere.

Conclusion

Creative problem-solving components were integrated into microelectronic course using 'visual representation' activities that allow students to capture or transform engineering problems into visual forms in a speedy but creative way. Particularly, a series of CPS exercises in the classroom were designed for students to identify the problem, to reflect on what they have already learned, and then undertake active inquiry and deep research on subject matter, brainstorming that propels imaginative and divergent thinking from different perspectives; visualization and creation of unorthodox creative solutions, and contextualization linking between creative ideas and the underlying principle of the subject. It looks like that students perceive visual representation practices as creative and thought-provoking processes that allow them to better understand the subject, rather than memorize the equations and key characteristics. In addition, an initial assessment indicates that students had better understand of microelectronic devices and applications when they are learning them through visual representation methods.

References

[1] ABET homepage; https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/

[2] Charyton, C., Jagacinski, R. J., Merrill, J. A., Clifton, W., & DeDios, S. (2011). Assessing creativity specific to engineering with the revised creative engineering design assessment. Journal of Engineering Education, 100, 778-799.

[3] Dewulf, S. & Baillie, C. (1999). CASE: How to foster creativity. London, UK: Department for Education and Employment.

[4] Kazerounian, K., & Foley, S. (2007). Barriers to creativity in engineering education: A study of instructors and student perceptions. Journal of Mechanical Design, 129, 761–768.

[5] Stouffer, W. B., Russel, J., & Oliva, M. G. (2004). Making the strange familiar: Creativity and the future of engineering education. Proceedings of the 2004 ASEE Annual Conference and Exposition, Salt Lake City, UT.
[6] Machechnie, J.R. & Buchanan, A.H. (2012). Creative Laboratory Model for Large Undergraduate Engineering Classes. Journal of Professional Issues in Engineering Education and Practice, 138, 55-61.
[7] Liu, Z., & Schonwetter, D.J. (2004). Teaching Creativity in Engineering. International Journal of Engineering Education, 20, 801-808.
[8] Baillie, C., & Walker, P. (1998). Fostering creative thinking in student engineers. European Journal of Engineering Education, 23, 35–44.
[9] Fila, N.D. & Purzer, S. (2014). I'm Not the Creative Type: Barriers to Student Creativity within Engineering Innovation Projects. 121 ASEE annual conference & exposition. 9602.
[10] Sternberg, R. J., & Williams, W. M. (1996). How to develop student creativity. Alexandria, VA: Association for Supervision and Curriculum Development.
[11] Wilde, D. J. (1993). Changes among ASEE creativity workshop participants. Journal of Engineering Education, 82, 167–170.
[12] Osborn, A. F. (1963). Applied Imagination: Principles and Procedures of Creative Problem Solving (3rd Revised ed.). New York: Scribners.
[13] Muhammad Syawal Amran, Faridah Mydin Kutty, Shahlan Surat , Creative Problem-Solving (CPS) Skills among University Students, Creative Education Vol.10 No.12(2019), Article ID:96794,10 pages
[14] From The CPS Process and Learner's Model by the Creative Education Foundation, based on the work of Alex Osborn and Sid Parnes. Adapted by G.J. Puccio, M. Mance, M.C. Murdock, B. Miller, J. Vehar, R. Firestien, S. Thurber, and D. Nielsen (2011).
[15] Coleman, L. (2015). How drawing is used to conceptualize and communicate design ideas in graphic design: exploring visual representation through a literacy practice lens, WAC Clearinghouse
[16] Natalie, The value of visual representation. https://saladcreative.com/blog/the-value-of-visual representation/
[17] Kavakli, M., Scrivener, S.A.R. & Ball. L.J. (1998). Structure in idea sketching behaviour. Design Studies, 19, 485-517.
[18] Van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. Design Studies, 26, 101-122.