Visual Representation-Based Creative Problem-Solving

Gon Namkoong, Old Dominion University, United States

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Abstract
Engineering students need to develop creative thinking skills to confront contemporary problems. While many creative problem-solving (CPS) strategies are developed, a convergence strategy to come to the single solution still remains a priority. This is partly due to the lack of creative educational tools that can be readily adapted to various educational settings. Visual literacy was suggested as an augmented way of promoting creativity through creative thinking and deep reflection on what students experience when they draw or view images. However, visual literacy was not fully implemented into engineering education yet. To this end, visual presentation-based CPS strategies are designed in a way that promotes student engagement and creativity in an image-rich environment. Particularly, visual representation using rough drawings is designed to include five essential stages, namely fact-finding, problem-finding, idea-finding, solution-finding and acceptance-finding. A series of CPS exercises in engineering problems start with critical reflection in which students identify the engineering problem (fact-finding); reflect on what they have already learned, and then undertake active inquiry and deep research on subject matter (problem-finding); brainstorming (idea-finding) that propels imaginative and divergent thinking from different perspectives; visualization and creation of unorthodox creative solutions (solution-finding); and contextualization linking between creative ideas and the underlying principle of the subject (acceptance-finding). The initial outcomes are positive and highlight visual representation as a new and authentic experience and creative and thought-provoking processes that allow students to better understand the subject, rather than memorize the equations and key characteristics.

Keywords: Creative Problem-Solving, Visual Representation, Engineering Learning, Critical Reflection

Introduction

Contemporary problems are not explicitly defined and have multiple possible causes that are unlikely to be solved by traditional means. To efficiently solve such problems, engineering students need to develop creative thinking skills where creative problem-solving (Wilde, 1993; Kazerounian, 2007; Stouffer, 2004; Charyton, 2021) should be prioritized in engineering curricula. Recognizing this contemporary demand, the accreditation board for engineering and technology (ABET) 2020-2021 criteria emphasized engineering curriculum by identifying creative problem-solving skills as an essential component for improving the future of engineering and engineering education. In response to these trends, engineering courses are being designed to incorporate more innovative, creative problem-solving skills. To improve and expand creative problem-solving opportunities during 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 (Wilde, 1993). However, the question remains as to how students can be creatively motivated, practice, and exercise out-of-the-box thinking within regular courses. Many ideas and strategies for creative problem-solving (CPS) have been developed since Osborn (1963) integrated creative skills into solving problems. However, literature reviews (Zheng, 2013; Oson, 2018) indicate that more systematic research needs to support students' generic skills and knowledge construction through CPS.

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 between 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 linear thinking, 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 classrooms without compromising the existing standards and how to overcome barriers that impede the integration of CPS into engineering education.

Visual representation for creative problem-solving strategy

Typical CPS model involves five stages (Zheng, 2013), namely 1) fact-finding, 2) problem-finding, 3) idea-finding, 4) solution-finding and 5) acceptance-finding. At the phase of "fact/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 challenging 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 of the CPS strategy is to first involve a divergent thinking phase in which one generates lots of ideas and then moves on to a convergent thinking phase in which only the most promising ideas are selected for further exploration. However, engineering students are not well trained to perform a series of creative problem-solving for engineering problems in regular classroom settings. In this context, visual literacy into CPS model can be integrated to facilitate CPS exercises by making the seamless transition from divergent thinking phase to convergent thinking phase.

Note that visual literacy can promote students' synectic exercises as part of spatial reasoning and manipulation experience. Pun (2007) 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' (Baaki, 2019; Huybrechts, 2012) 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 drawings to visually communicate and articulate design ideas. Currently, visual representation is 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 present their conceptualization with hand-drawn representations or graphic tools. At a first step, visual representation can simply display '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 by paving new ways for idea generation in an individual generation-reflection-interpretation cycle. In the engineering classrooms, students can easily apply visual representation to face many engineering problems which allow students for grasping the underlying principles of the problems, reflecting and interpreting them from their own experiences and perspectives, and then transforming them into practical solutions.

Example of student visual representation

Initial implementation of visual representation has been applied to microelectronic course for electrical and computer engineering students. Students learn the principle of pn diodes that are used for numerous modern electronic devices such as light emitting diodes (LEDs), rectifiers, others. The principle of pn didoes contains numerous abstract formulas and principles. Visual representation was pilot-tested for students to master the underlying principle of pn diode physics. One of example of visual representation of pn diode is shown in Figure 1.

Figure 1: Visual representation illustrating pn diode.

Student essay for visual representation: "This visual representation describes a diode in relation to a pn-junction. When the positive end of the terminal, cathode, is connected to the p-type junction and when the negative end of the terminal, anode, is connected to the n-type junction it creates a forward bias within the circuit. A forward bias within the circuit means that there is little resistance within the circuit which creates current. When the cathode and the anode switch junctions to where the anode is connected to the p-type and the cathode is connected to the n-type, it creates a reverse bias. A reverse bias creates a lot of resistance in the circuit to where there is little or no current flow. Within my drawing we have two main characters: the cat named "Cathode" and the bunny named "Anode." Cathode and Anode are participating in a two-man bike race. Each set of pedals represents the n-type or the p-type junction. In the start of the race, Cathode is connected to the p-type junction and Anode is connected to the n-type junction. This creates the forward bias from the first paragraph, and they start to win the race because of the flow of current. They are going so fast Anode wants to try to steer so he jumps up front, reversing the connection. Now Anode is connected to the p-type junction and Cathode is connected to the n-type junction. This creates no current and a resistance barrier that the characters end up crashing into. This illustration is my attempt at a creative way to show a pn-junction."

Figure 2 shows another 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. In this case, visual representation method has been applied where students visualize the principle of MOSFET, shown in Figure 2. Student clearly show the role of source, gate and drain where the MOSFET current flow is clearly visualized.

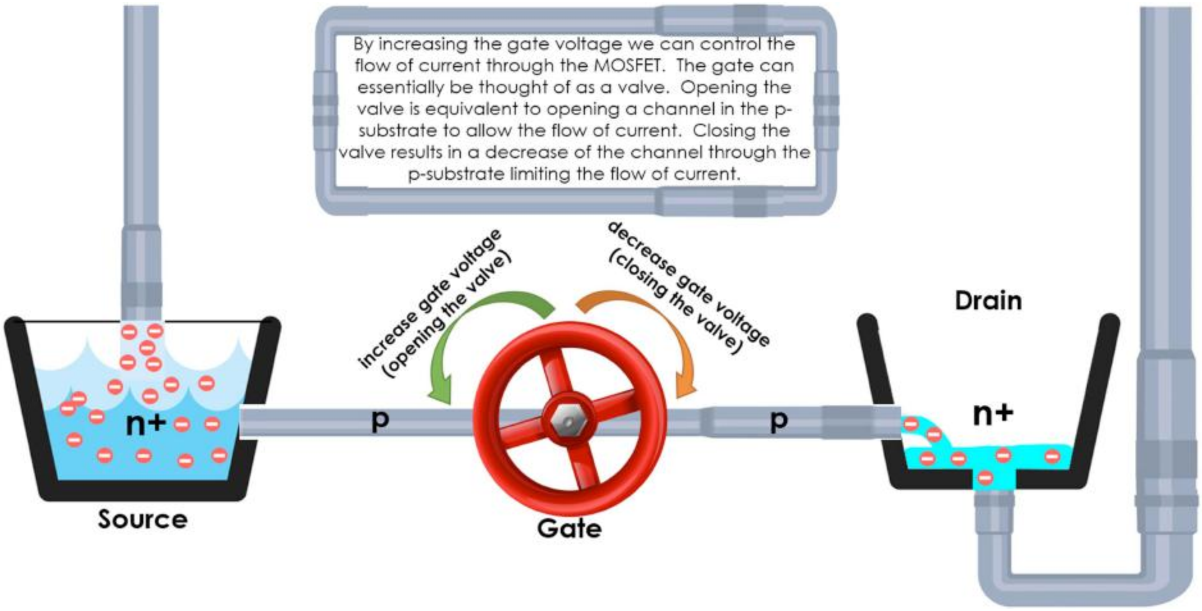

Figure 2: Visual representation illustrating the working principle of metal-oxide field effect transistor (MOSFET).

Student surveys from pilot study

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. Below are comments from students.

> 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.

> 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 metal oxide semiconductor field effect transistor (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 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 visual presentation 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 visual representation essay. I really liked this assignment and I think it's something that you should continue with in future classes.

> 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.

Conclusions

Visual representation method has been implemented to engineering microelectronic course where lectures were firstly delivered to students and then students were tasked to work on the engineering problems with visual representations. In this case, many different visual representation formats can be used including rough sketches, pictures and other media formats. The initial implementation of visual representation to engineering course showed the students' positive responses toward visual representation where students enjoy an involvement of creating visual representation and consider it a creative way to develop creative thinking skills. In addition, students are willing to apply such visual representation method to other courses. Further evaluation including students' creative problem-solving skillsets – fluency (number of ideas), flexibility (different types of ideas), and originality, application to various hands-on laboratory projects; and students' perception, academic and personal achievement, retention, barriers and enablers through creative problem-solving will be pursued.

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