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Adopting Engineering Problem Solving Framework for Applied Art Training

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In this paper, I will share my experience of how an engineering problem-solving framework can be adopted as an effective art pedagogy, especially for training applied art students. The major difference between applied art and fine art students from the perspective of training outcomes is the difference in their professional practice. While a fine artist is involved in constantly exploring new ground, an applied artist is also required to perform a task to fulfill the field-specific demand. While a fine artist may create a sculpture for sole visual enjoyment, a product designer needs to develop a product for its physical application. A car has to be driven. A cup has to hold liquid. Therefore, to tailor the needs of applied art students, a structural approach has its advantages. A new pedagogical approach borrows from the robust structure of engineering and scientific problem solving, the cause-and-effect diagram (also named the fishbone diagram) to develop a training approach for applied art foundation students. This engineering framework illustrates how a complex art-creating process can be deconstructed. Hence, variables can be introduced to make the overall creative exploration more efficient. A few students shared their experiences after participating in this art training approach.

Keywords: cause, effect, fishbone, art, Ishikawa

Introduction

COVID-19 has speeded up the way educators need to relook at the effectiveness and efficiency of different types of training. In art schools, studio-based training was a norm before COVID-19. Face-to-face education is considered the most direct interaction that students can have either for fine or applied art. Covid has since shifted the norm. Online learning and emergency remote teaching have started to be in demand. Therefore, the effectiveness of various remote learning models was studied and compared (Barbour et al., 2020). While fine art and applied art do not share all common objectives, this study focuses on how a structural approach could influence applied art skill training. In a way, the approach may also be argued to have a similar impact on any form of remote learning. This is supported by another research that shows the advantages of the systematic approach that is used in online learning (Hodges et al., 2020).

The commonly agreed difference between applied art and fine art outputs is the predefined outcomes are anticipated from applied art within a preset timeline. While both art forms produce creative solutions, applied art is limited by additional constraints which may include producing pre-defined outcomes or business requirements. Coincidentally, its problem structure and working function match how an engineering team resolves daily issues. Therefore, this study aims to understand the

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feasibility of adopting the engineering problem-solving framework for applied art training. The research questions may summarize the scope of this study.

> Research question 1: What are the aligned logics observed between applied art training and engineering problem-solving?
> Research question 2: What are the differences between a traditional art training method and an art training experiment using the engineering problem-solving framework? What are the strengths and weaknesses of the latter based on interviewees' feedback?

Literature Review

As argued by the principle of constructivism, learning is a process of searching for meaning therefore the answer lies in the individual who constructs the meaning. This process involves building the outcome based on an individual decision. Coincidentally, it is remarkably similar to an artist's creative process, in which the artist decides and defines the final output. The constructivist's instructional model also emphasizes students developing independent solutions while promoting learning that links personal creation and practical skills. These factors are again parallel to an art student's learning outcome, especially for an applied art student who is required to face field issues while maintaining creative outputs (Xuemei & Lixing, 2011).

The training based on a constructionist's concept states that education should aim to develop a student's ability to learn how to learn, to resolve problems independently, and to invent new solutions (Xuemei & Lixing, 2011), while inquiry-based teaching and learning similarly state that it teaches real-life practical skills. The latter is comparable to engineering training (Guo & Lu, 2011). Therefore, this indicates a linkage between professional training for both engineering and applied art.

When engineering education is mentioned, problem-solving skills and frameworks immediately come into the picture. Problem-solving is the core of engineering training. Engineers from theoretical research to frontline manufacturing of final products, all involved in technical problem-solving.

Looking at another area of study related to the instructional model, the 8 principles of the instructional model suggested by Savery and Duffy (1995) for problem-based learning (PBL) may clarify the detailed structure of learning. First, it requires the learner to have a clear understanding of the problem to be resolved. In principles 2 to 5, the authors further argue the importance of ownership for the learning process to be effective. The teacher acting as a consultant may dictate in defining the learning scope, while students though constrained by the scope, define and construct their learning centralizing around the pre-defined problem. The working process aims to expand the perspective of learning than restricting students through procedural instructions. The learners have the freedom to search for new possibilities in solving their defined problem under the big umbrella of a pre-defined problem statement. Principles 6 and 7 support students' freedom in exploring new grounds while principle 8 is a reflection process of students' learning. These 8 principles align well with both training in applied art skills and engineering problem- solving.

Starting with principle 1, a learning objective is defined. For applied art skill training, any technical skill acquired is targeted to resolve specific issues though some skills may be very fundamental like color theory or design concepts. Therefore, a clear learning objective is always set. Principles 2 to 5, require the learner to own and design the task and further set the working constraints. This is common for art students. Based on a topic learned each art student will creatively decide their practical outcomes while working with the principles or theories taught. Principles 6 and 7 require the instructor to function as a facilitator to challenge students' views and moves during the search for a solution and encourage the students to discover new possibilities through accepting alternative views or changes of contexts. That is exactly how an art instructor functions. The instructor only provides feedback and critique after looking at the progressive outputs of each student while the outcome may all be set differently. The art critique sessions align well with Principle 8 to provide the opportunity for the students to reflect on the overall learning process and outcomes (Savery & Duffy, 1995).

These steps further align with the engineering problem-solving process. An engineer first defines the problem or is tasked with it. The engineer during the search for a solution, collaborates with a team of other professionals who may provide different guidelines, knowledge and/or constraints that help the engineer generate the most cost-effective solution. This reflects the open structure of how an engineering solution is developed. Compared with applied art training, similar working logic can be identified.

As the engineering environment is fast with the current speed of technological advancement, its problem-solving framework has been robustly developed. Engineers could therefore fully rely on this tool and respond to issues efficiently. Therefore, it is worth studying how applied art training may borrow the knowledge of engineering problem-solving. This framework may assist applied art pedagogical development in identifying the most efficient learning process and defining the most appropriate logic for the learning outcomes.

Methodology

The research adopts the quality methodology as the major portions of the research work were related to a comparison between the engineering problem-solving structure and the applied art training pedagogy, my personal engineering and art teaching experience, and training and quality interviews of participants' learning experience. Below are the procedures:

First, the nature of the creative process was compared to the engineering problem-solving approach to understand their structural similarity or differences. It was followed by my experience sharing when an engineering problem-solving approach was adopted for training art students. The fishbone diagram serving as the heart of engineering problem solving, was adopted to demonstrate its capacity in analyzing and resolving a technical applied art issue.

In total 5 art students participated in the qualitative interviews and provided feedback related to 3 topics, namely, the current mainstream art training and its issues, their experience with the engineering problem-solving approach and the strengths and issues using an engineering problem-solving approach for art training. These 5 students were selected because they had also experienced diverse types of art training before they participated in using an engineering problem-solving approach for their training. The interview questions asked are listed below:

1. Briefly discuss any of your other regular art training classes. did you see a specific training model any of the instructor was using?
2. What do you like about the training approaches?
3. What do you dislike about the training approaches?
4. Did you know before you participated in the research that the trainer was using an engineering problem solving approach to conduct applied art skill training?
5. What are the strengths and weaknesses the engineering problem solving approach when it is used to train applied art skills?
6. Do you have any other feedback?

Results & Discussion

Comparing Creative Process and Engineering Problem-Solving

Visual art skill training involves developing students' creativity. Training of creativity somehow is thought to reject any procedural process of instruction. However, the difficulty also lies in defining the level of freedom in instruction. Therefore, the training may borrow learning and problem-solving process that are highly similar to an artist's process of art creation as described by Savery and Duffy's problem-based learning (PBL) approach – the constructionist's framework (Savery & Duffy, 1995). Below, I use an example from my teaching of value design (or tonal design) in drawing and painting as a comparison.

An assignment given to art students only broadly mentions the scope while students have the freedom to explore and define their problem statements differently from one another. For a value design exercise, students first define the mood or weather they prefer. This aligns with principle 1 when the student defines and owns the problem. The research, exploration, trials, and drafting process again align with principles 2 to 5 of the instructional (Savery & Duffy, 1995). Students, thereafter, carry out their research related to their defined weather or mood (Ng, 2020). The research could cover historical images from master artworks, observations of real situations, and explorations based on the instructional concepts provided by the instructor. Each student owns the problem and directs one's working process, while the instructor may provide guidelines. Aligning with principles 6 and 7, the art instructor acts as a consultant during students' explorations. The art critique process aligns with principle 8 as elaborated in the literature review (Schön, 1987; Clift, Houston, & Pugach 1990). It provides feedback on the submitted assignments. Therefore, what applies to PBL should work well with applied art training.

Coincidently, PBL also aligns with the engineering problem-solving approach. Engineering training involves planning, the design of experiments, data collection, forming a hypothesis thereafter proposing the most feasible solution and anticipating outcomes. A parallel comparison between engineering problem-solving and applied training is shown in Table 1.

Table 1. Comparing Engineering and Applied Arts Training Scopes

Stages	Engineering	Applied Art
1	Problem Statement	Problem Statement
2	Planning, exploring, and brainstorming. Define modular approaches and sub-tasks	Planning and drafting. Deconstructing the problems to multiple sub-tasks.
3	Research	Research
4	Forming hypotheses, defining the possible working direction	Selecting probable working variables for explorations
5	Designing and executing experiments, and collecting data	Experimenting with selected variables and drafting various possibilities.
6	Analysis of data and conclusion. Coming up with recommendations.	Image analysis finalizing the working process and completing the assignment. Providing critique.

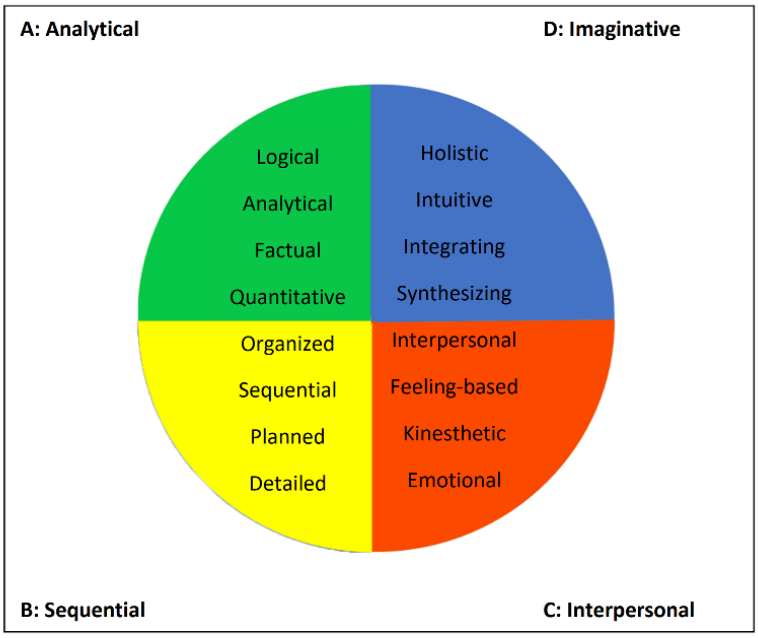
Each engineering stage aligns with the work scope of an applied artist. While an engineer uses a Pareto diagram to define the most critical problem, an applied artist is given a pre-defined outcome to achieve or a self-directed target to work on (Table 1, Stage 1). The most relevant and important items that the applied art training may borrow from the engineering problem-solving framework are stages 2, 3, 4, and 5.

Engineering problem-solving is based on the cause-and-effect diagram (also named the fishbone diagram) developed by Ishikawa (1985). The idea-generating process for the cause-and-effect diagram is done through a brainstorming process (Lumsdaine & Lumsdaine, 1994). The process of brainstorming covers all the possible areas of the causes of the problem, including manpower, machines, measurements, materials, methods, and environment summarized as 5M1E (Koripadu & Subbaiah, 2014). This forms stages 2 to 4, from planning, exploration, research and defining possible working direction. In applied art, the fundamental visual art elements are equivalences. For example, the presentation of the mood of an image is related to the selection of tone, color, shapes, and space. While the problem may be deconstructed in applied art or engineering, some input factors may be interdependent. These interdependent parameters make the adjustment of each parameter more complex. Therefore, the advantage of a robust framework is immediately recognized. It allows a less sophisticated entry. Identifying influential input factors becomes the most important initial step before dealing with the interdependence of certain input factors.

Due to the complexity and possible interactive factors within the 5M1E, in stage 5, an engineer carefully designs experiments, managing and blocking factors to identify the causes of a defined issue and the effect. If an artist could borrow a similar thought, the creative exploration process can be controlled within a more probable scope. This improves the process of identifying more potential causes hence reducing unnecessary exploration of less likely factors. As applied art is part of a business operation, timesaving is therefore critical as part of the resource-saving process. Therefore, this paper studies the possibility of using this systematic training approach for applied art students working with creative ideas. That is also coincidentally supported by the study of *'Classroom Teaching Through Inquiry'* in which both cause and effect framework and creative idea generating are discussed together as part of the whole training process (Buch & Wolff, 2000).

Another piece of evidence is from Hermann's Whole Brain Model (WBM). Hermann's Brain Dominance Instrument (HBDI) suggests four quadrants of different brain functions. Each quadrant governs diverse ways of thinking. Quadrant A of the HBDI relates to analytical thinking which is connected to logical, factual, technical, and quantitative analysis. Quadrant B structures the thinking process in proper sequence, connecting closely to the problem-solving process. In quadrant C, the interpersonal skill is less relevant to this research, while in quadrant D, the imaginative motive is highly relevant to artists searching for new ground or the unknown (Herrmann, 1999). The finding further confirms that creativity is not confined to a certain HBDI thinking quadrant. It maps across different quadrants (Herrmann, 1999; Lumsdaine & Lumsdaine, 1994).

Figure 1. Four Quadrants of Thinking Modes – Hermann's Whole Brain Model



Source: The theory behind the HBDI and Whole Brain technology. Better results through better thinking (Herrmann, 1999).

Meneely and Portillo also summarized based on Goldschmidt's study of the creative design process that creativity is a parallel process through different combinations of all four quadrants of brain functions. *'The ability to synthesize a novel concept with a myriad of programmatic constraints becomes a hallmark of the successful designer'* (Goldschmidt, 1999; Meneely & Portillo, 2005). The authors further mentioned that *'When students were less entrenched in a specific style of thinking they measured higher creativity using Domino's Creativity Scale.'* (Meneely & Portillo, 2005).

A design process study has indicated that the process involves two distinctive parts. First, the open-ended process allowed students to explore ideas based on their personal preferences. However, the second process imposes constraints to provide functionality with that design (Amabile, 1983). This aligns with the engineering problem-solving process while an engineer has the freedom to use any ideas to overcome an issue, there are desirable outcomes to fulfill within prescribed engineering constraints for example a maximum allowable value of an adjustable machine parameter.

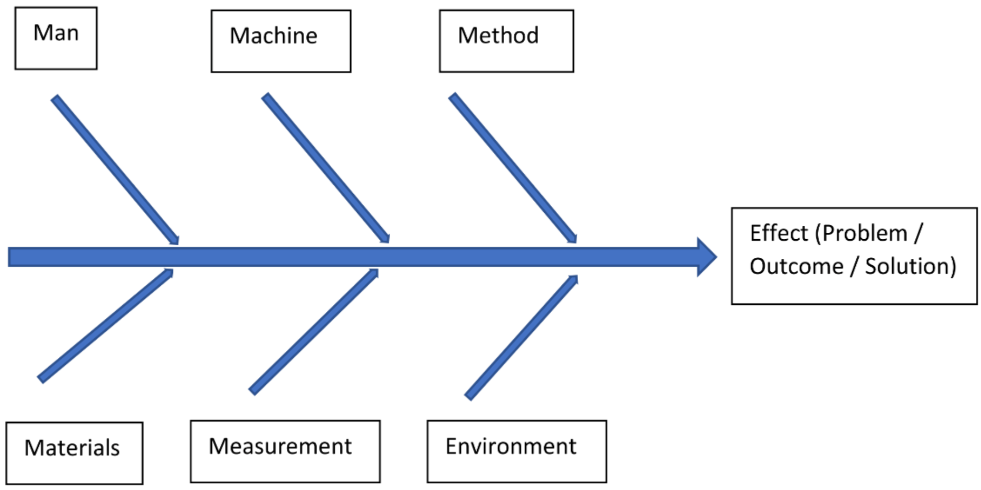
A discussion related to the integration of problem-solving with engineering design also shares many similar characteristics of how an applied artist will develop an artwork. It involves idea generation. It is carried out through planning which leads to a brainstorming process. This is highly similar to an early-stage artwork development process - the imaginative, synthesizing, and intuitive process in artmaking. Another stage that is also comparable to the art-making process is the idea judgment stage. In this stage, both engineering design and art-making involve critical thinking and decision-making (Lumsdaine, Shelnutt, & Lumsdaine, 1999).

The analytical and structural approach of engineering design and planning may not be completely relevant to fine art, but it matches well with applied art. Applied art needs to respond to its market demand or its client's requirements. A structured and analytical process maximizes the output and minimizes the waste of resources in working on less feasible trials. Engineering problem-solving in industries requires a systematic and fast response to avoid unnecessary delays working in highly stressful environments. How does an engineer handle that? The answer lies in the system provided. The system here refers to a robust framework that has been developed in all the mature engineering industries. As the problem-solving structure is robust enough, an engineer does not have to go under the stress of not knowing how to proceed in front of a complex issue. Sometimes, the technical issue could even involve a new area of science that is waiting to be discovered. The problem-solving framework though does not provide an immediate answer to the challenge, it serves as a robust framework for the search for feasible solutions. In the applied art industry, similarly, artists working on a task are given a time limit. Adopting the same working framework reduces unnecessary working stress when creative solutions are evolving.

The formal documentation process in design engineering is another process that is highly relevant to applied art. All the experience and exploration processes through a proper documentation process make every discovery or invention transferable. This benefits any future research and sharing of resources (Lumsdaine, Shelnutt, & Lumsdaine, 1999).

Epstein and peers discussed the benefit of broadening the skills of a professional as a process of nurturing creativity (2008). The brain-storming process within this engineering approach is similar. It pushes the engineer to step into areas that they are less familiar with. Comparing Dali's artistic process with this engineering problem-solving approach, either the process of capturing ideas from 'dreams or daydreams' like Salvador Dali or the broadening of knowledge for generating new ideas. Dalí (2013) and Mavromatis (1987), are both similar to the brain-storming process of engineering problem-solving. An engineer has to constantly look for an innovative move to solve problems because most of the high-tech engineering field does not accept progressive improvement. Not surprisingly, most will require a quantum-leaping level of improvements. For example, in the storage industry, from 128Gb, the next will be 256Gb which is a 100% improvement. No one will accept 129Gb as an improvement. Therefore, the process of electronic innovation is called the state of the art. Just like artmaking, artists could not be satisfied by repeating what can be done and just doing it a bit better. Therefore, the idea-generating process becomes critical to both engineers and artists. The structural and innovative tool used by an engineer is described in Figure 2.

Figure 2. The Fishbone Diagram for Engineering Problem-Solving



Source: Using fishbone diagrams in inquiry-based teaching and learning for engineering education. International Conference on Information and Management Engineering, Berlin, Heidelberg (Guo & Lu, 2011; Ishikawa, 1990).

Figure 2, the fishbone diagram invented by Kaoru Ishikawa in 1943, is also named the "Cause and Effect Diagram", looking like a fish skeleton (Guo & Lu, 2011; Ishikawa, 1990). Therefore, it is often referred to as the fishbone diagram. It acts as a systematic problem-visualizing tool to assist engineers or scientists in investigating all the major or possible factors related to a defined problem or targeted output. The causes are modularly categorized. The effect is a defined problem or an objective set by the user (Liliana, 2016). Guo discussed how the fishbone diagram could work together with the inquiry-based teaching approach. Based on the inquiry-based teaching approach, the diagram was capable of nurturing engineering students' creativity. Students demonstrated self-analysis and critical thinking through this investigative journey. It diverted students from accepting prescribed solutions (Guo & Lu, 2011). The brainstorming process working like mind mapping, pushes students to discover new possibilities instead of accepting the obvious (Koripadu & Subbaiah, 2014). A renowned watercolor instructor Robert A. Wade discussed the need to 'engineer' tones of an image as an important part of the whole compositing process. He uses the word 'engineer' which matches exactly with engineering practice.

'… you will come to realize you can engineer changes. …' (Wade, 2002, pp. 18-20, 27). His statement further indicates the need to have a structured process to work

with image design. Based on his argument, for example, the tonal design of an image can be carried out. In the next sub-section, I will elaborate on how the fishbone diagram can be applied to design the mood or weather of an image through a deconstruction process.

Experimenting with the Engineering Problem-Solving Approach as an Art Pedagogy

While I am an experienced visual artist and an art instructor, I was also trained as a professional engineer. I had nine and a half years of engineering experience working in the high-tech electronics industry. My daily routine was to carry out experiments, to continuously come up with innovative solutions or quantum-leaping breakthroughs. The engineering problem-solving framework was the most effective tool which helped me modularly explore different areas of possibilities to arrive at innovative solutions.

While the nature of high-tech engineering work is vastly different from artmaking, I have realized the usefulness of this modular process in isolating complex variables and later learning their interdependence if that does exist. Being able to isolate input parameters, I am able to explore each modularly. There are two significant advantages.

The first advantage is the ease of knowing the impact of a change made or technically termed as an input variable introduced. The responding signal is stronger when a parameter can be well isolated in an experiment. A similar approach is practiced in art training or an artist's drafting process: - the black-and-white drawing. Therefore, it has been one most important foundations of art skills at all art institutions for hundreds of years. To elaborate on its practicality, before working in color, painters like to explore their compositions in black and white. It is called the tonal or value design process of an image. That helps artists focus on just one attribute of color, the tone[1]. Hue and chroma are temporarily removed to reduce the complexity during this early composing stage. Hues can be later matched with the values designed.

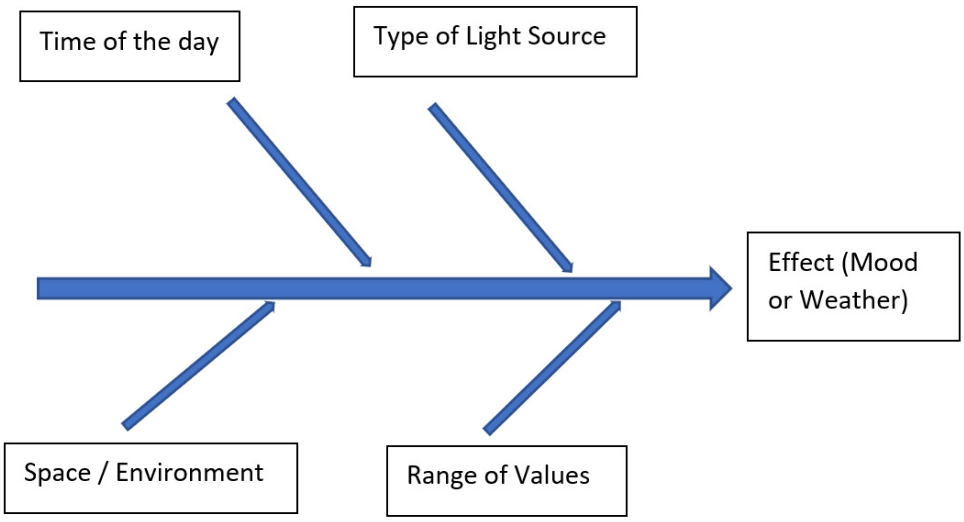
The second advantage is that it reduces the scope of the trial-and-error process. When the range to explore is well defined, it enables the artist or the student to progressively explore each parameter within or outside the commonly accepted scopes. A common misunderstanding of the creative process by laypeople or entry-level students is that they think trying out things randomly with a lot of courage is creative. However, in reality, all human beings have certain behavioral habits and are bound by these constraints. Here is an example that I have observed many times in drawing classes. Many entry-level students may think that when they are drawing randomly, they will arrive at a higher level of creativity. However, they do not realize that those 'random' actions are also bounded by many pre-set parameters or they may be termed as constraints, for example, one's strength, size, length of hands, and preferred materials. All these parameters form many layers of constraints. In the end, they are repeating their drawing habit without knowing it. A study related to human habits answers this well. The study has shown that habits are associated with desirable outcomes and are strengthened slowly. To inhibit a behavioral habit, one

[1]Tone: Tone or value in visual art indicate the lightness. It is indicated in gray scale (black and white). It is one of the 3 most common attributes of a color, namely value, hue and chroma.

effective way is to introduce a different context. The change in context can be the environment or an imposed variable that intentionally suppresses the person's habit, while the person knows it (Wood & Rünger, 2016). The author used an example related to eating habit change. It has been shown that an unhealthy eating habit can be improved if the accessibility of those foods is reduced (Sobal & Wansink, 2007; Wood & Rünger, 2016).

Therefore, in order to discover a new solution or to be innovative, a structured framework may serve as a good guide. It indicates that a new variable introduced is a true change. This cannot be done by a random choice. It has to be structured so that the artist knows that he or she has intentionally imposed a change. Therefore, the outcome can be studied, analyzed, or correlated to the newly input parameter. This is so similar to an engineering experiment. Moreover, an applied artist has a commercial requirement that a fine artist may not need to worry about. For a fine artist, one may just produce a result for only one occasion. Even if the outcome is accidental, it is acceptable. However, for an applied artist, the successful work process has to be documented so that in the future others can adopt the same method for a similar result. This improves the efficiency of a commercial art operation and minimizes the waste of resources in the business.

Figure 3. Using the Fishbone Diagram for the Value Design of the Weather and Mood of an Image



Source: Adopted from the fishbone diagrams in inquiry-based teaching and learning for engineering education. International Conference on Information and Management Engineering, Berlin, Heidelberg (Guo & Lu, 2011; Ishikawa, 1990).

I use Figure 3 to demonstrate how to 'engineer' values to create the required weather or moor for an image. The causes (5M1E) in Figure 2, can be converted in parallel to visual art parameters to generate the required mood or weather. For the construction of the weather of an image, the fishbone can serve as a deconstruction tool to understand the factors that need to be adjusted to compose the weather. The four most relevant inputs are identified, namely the time of the day, light sources, the space, and the range of values that are related to the weather. Below is the further deconstruction process of each factor that will help students understand the importance of each factor though some may be interdependent.

The time of the day will suggest the major types of values to be applied. The space or environment will determine how the light will behave. Will it be blocked or reflected? For example, during a rainy day, the main portion of the light comes from the sky while the rest is blocked by buildings. The wet floor will reflect some light. The type of light source is another influential factor. Natural sunlight is coming in a parallel direction, while artificial lighting will radiate and reduce in strength based on a spherical model across the space. The last factor, the range of values is an interdependent factor to the time of the day and types of light sources. For example, if we design a night scene, dark values will dominate, while the light sources are artificial and will gradate in a spherical manner (Ng, 2020). With this process, a complex art-making issue can be deconstructed and resolved modularly just like an engineering problem. Five students who had experienced this problem-solving approach were interviewed and their responses were discussed in the next few paragraphs.

Art Students' Feedback

Five art students who participated in art training classes (drawing or painting classes) that had adopted this engineering approach were interviewed. These 5 students are identified as ST1 to ST5. They also experienced other art training methods before participating in this type of art training.

The Mainstream Art Training and Issues

The invited students' feedback indicated that there were two mainstreams of art critique and instruction. ST1 (personal communication, July 11, 2020) and ST2 (personal communication, July 11, 2020) shared their experiences. The first type of training is a common 'fine art' based training. Normally, students are given choices based on their interests and ideas. It encourages exploration. Students benefit from the process of trial and error. However, ST1 felt that this approach was not effective in cultivating technical skills. During the critique, the instructor provides subjective opinions based on his/her experience, personal feelings or emotional response. The advantage is that the critique may open many possibilities. It allows students to bring in solutions from any professional area without much restriction. It shows the flexibility of how a fine artist is able to borrow knowledge from any area and reinvent it as a fine art output. However, entry-level students without a wide range of knowledge and experience may feel aimless. Moreover, students will have a tough time learning why or how the instructor has arrived at his/her critique. Therefore, it is harder for students to transfer that knowledge to future applications.

A second type is a prescribed approach. The instructor provides procedural steps for students to arrive at a predefined outcome. While it is efficient in transferring skills, it restricts explorations. For a drawing class, a student ST4 (personal communication, July 3, 2020) reflected that one instructor favored only the Disney/

Pixar drawing style in animation. Exploration of other approaches was not encouraged. Another student ST5 (personal communication, Dec 24, 2020) also agreed that this approach would blindside students and make them think those taught models were absolutes in art. While this is a problem, ST2 also found the benefit of this restricted approach. She realized that this approach was highly effective in transferring the instructor's skills to students and that the instructor could provide very constructive feedback to students. She also felt that entry-level students might need to build up more practical muscles before they were allowed to freely explore any area.

ST1 also reflected that due to the procedural approach, the class was very structured and it, therefore, felt more cohesive. Work was allocated in chronological order and the difficulty level built up progressively. According to ST1, the students who would benefit most from this approach were those who practiced a lot. ST5 also pointed out the benefit of being able to see the instructor's demonstration as well as the instructor's immediate guidance during the studio art classes. He further pointed out the weakness. Students, therefore, have very few chances to explore ideas or methods outside the defined scope as they have to focus on achieving a confined objective set by the instructor.

Students further responded about the differences in the engineering problem-solving approach as compared to the two mainstream art training approaches discussed above.

Art Students' Experience with Engineering Problem-Solving Approach

Students' feedback also resonates with my experience discussed in the literature review. ST1 realized that she could identify the root causes. Therefore, it enabled her to solve complicated art-making problems after combining all the modularly identified causes. The clarity of this problem-solving process also made her feel that her art-making process was more satisfying as she was able to apply all her acquired concepts with confidence. Similarly, ST2 also appreciated that the complex and intuitive art-making process could be fragmented modularly with the engineering problem-solving structure. In general, she did not anticipate that the art-making process could be taught in such a structured manner and could resolve issues with clarity. She responded positively by saying *'It was eye-opening that the mystery and "magic" behind drawing and painting could be explained using math and science… Magic is magic when it can't be explained. The formal language used in image making could be explained and be learned by every student.'*

ST3 (personal communication, July 2, 2020) also resonated with ST2's response by mentioning that this structured process had helped him realize that art and technology were not completely different. He further suggested that this learning concept should be reinforced for art students. He appreciated scientific reasoning in resolving art issues. That aligns with the first advantage that the causes of an issue can be seen clearly. The causes of the issue are also identified objectively. ST4 further mentioned that it had helped her break down complex issues. She used her learning of figurative drawing as an example. This process helped her simplify the drawing of form and she was then able to reconstruct more complex forms. She commented that the engineering mindset had provided her with a tool to isolate factors. That helped her understand how an issue was connected to each input variable. In this case, the input is well isolated. It provides a better output signal. That also helps in determining the effectiveness of each change introduced.

She further responded that this process had helped her depart from prescribed outcomes. This shows that the problem-solving process instills creativity and helps a student uncover his/her capacity. ST5 also responded similarly by saying that the understanding of the science behind the art-making process had enabled him to discover art in greater depth.

Issues and Possible Improvements Using Engineering Problem-Solving Approach for Art Training

ST1 responded that this engineering approach was unorthodox to art students because her common experience was that art students would work more with personal instinct while this approach removed their instinct. Engineering problem-solving requires users to work with reasoning and logic related to an issue raised. Therefore, she responded that students might require more time to gain experience working with this approach. Moreover, she also felt that this scientific approach could be too idealistic. ST2 responded similarly, thinking that it would be difficult for students who did not have sufficient technical art skills to identify the relevant issues. She felt that students required more time to build up their technical art skills. For example, a beginner may need more practice in drawing and painting they have sufficient visualization power to appreciate this problem-solving approach. Otherwise, they may not visualize the importance of each input factor. ST4 also indicated that students who did not practice enough might not appreciate the advantage of this approach. Their response aligns well with how an art student develops his/her visual sensitivity. Some subtle changes like a minor shift in hue or edge softness will require a lot of practice. Technically this engineering approach may require students to drill repeatedly to gain sensitivity to those more subtle input visual factors. ST5 even suggested bringing in real-life issues in the art industry for students to experience the strength of this approach. In addition, as reflected by ST3, some art students might still prefer to work with an intuitive approach instead. However, the advantages of this engineering problem-solving approach are not lost even if it has the abovementioned issues. These issues can be overcome with some effort in the design of exercises. I would argue that as long as the difficulty level of the exercises is managed well, the benefit of this approach will be appreciated.

Conclusions

With this framework, it removes the risk of students following a prescribed approach to arrive at only a predetermined outcome while it does not encourage aimless or random exploration that may waste resources or efforts. It also reduces students repeating a habitual and random response and thinking that it is a creative act. Therefore, it carries the strength of both mainstream art training approaches mentioned above as it is not prescriptive. It allows a certain level of open exploration. However, it also does not suggest openness without constraints. It sets constraints so that students understand that they are exploring every parameter with a thoughtful mind. Therefore, with the help of this structured process, aligning with Epstein, Schmidt, and Warfel's (2008) argument and Guo's (2011) study, it expands students' ability to discover the areas of the unknown (Koripadu & Subbaiah, 2014). The framework further assists students in learning and working with more complex issues when input parameters may sometimes have interdependent behaviors.

Art students gain the ability to construct their learning and develop a robust structure that will match the needs in the applied art industry especially. It reduces the unnecessary stress of working in a high-stress environment where time and resources have to be efficiently utilized to generate business profit. However, more research effort is required to compare the difference between this engineering approach against the intuitive art approach to understand their strength and weaknesses so that when this engineering approach is introduced to art students, it does not reduce the intuitive talent of art students.

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