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Integrating Visual Thinking into Design Education

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Introduction

Vision is one of the first senses to develop in infancy, starting with facial recognition and object tracking [1], [2]. As the visual system matures, it supports memory, cognition, and perceptual development—processes that are crucial for imagination, creativity, problem-solving, and idea generation [3]. Visual perception can be understood as a deterministic process from an evolutionary and neuroprocessing perspective, aimed at extracting information from direct or scattered electromagnetic energy [4]. However, perception can also be viewed in a more nuanced way, as the integration of visual sensory input with other sensory information, stored memories, and experiences, alongside intentional cognitive processes such as visual thinking [5]. Understanding both deterministic and integrative perspectives on perception provides a foundation for exploring how visual thinking supports cognitive processes essential in fields like engineering [6]–[10].

Building on this, engineering education traditionally emphasizes modes of thinking such as mathematical, scientific, analytical, and systems thinking [11]. However, at its core, engineering relies heavily on design thinking—a process deeply dependent on visual thinking for idea generation and problem-solving [12], [13]. Despite its importance, formal instruction in visual thinking is often missing from engineering curricula. This gap in visual thinking instruction limits students' ability to fully engage with the design thinking processes central to engineering. In the United States, visual thinking skills tend to decline after the sixth grade, with further erosion during secondary education due to the absence of formal coursework [14]. Instead, the focus shifts to subjects that prioritize mathematical, verbal, and analytical skills. By understanding the deterministic aspects of visual perception and cultivating visual thinking skills, engineering students can strengthen cognitive abilities critical for communication and effective problem-solving, including critical, statistical, and design thinking [15].

The ability to engage across multiple modalities, operations, and levels of thinking is vital for creativity, problem-solving, and learning. Among these, visual thinking—broadly defined as the cognitive ability to process information through mental imagery, pattern recognition, and spatial reasoning—stands out as particularly important for engineering.

In an era where digital technology dominates communication through visual information sharing, the rise of manipulated images, data, and videos in social and creative spaces highlights the need for engineers to master both the ethical generation and interpretation of multivariate visual information. Furthermore, failures in visual, statistical, and graphical thinking can result in distorted data, flawed scientific conclusions, and poor engineering decisions [16]. Moreover, our reliance on digital technology risks oversimplifying complex realities, further hindering the development of visual thinking skills. Therefore, it is essential for engineering students to understand not only the processes of visual perception and thinking but also how engineered systems can be used to distort causal relationships. It is also critical for students to understand the potentially addictive and harmful effects of AI-driven screen communication technologies, as well as the ethical implications of contributing to their continued development.

Perception is not a passive process; it is intricately connected to visual experiences and memory formation, especially episodic memories, which play a vital role in cognition during engineering design. By more fully integrating visual thinking with other cognitive modes, we can enhance creativity and problem-solving abilities. As a result, teaching these skills is essential in engineering education.

The absence of visual thinking skills can impair cognitive processes such as causal, critical, statistical, and graphical thinking, as well as abilities in ethics, design, data interpretation, and problem-solving. Visual thinking involves pattern and object recognition, performing mental operations on visual information, and engaging both conscious and unconscious thought processes. It also enables the formation of mental images and the creation of both analog and digital representations of what we see and imagine, which are crucial for effective communication.

Although visual thinking and inner mind imagery play a critical role in creativity, they are not the only factors. Openness to experience, conscientiousness, motivation, flexibility in thinking, curiosity, and environmental factors—such as genetics, early childhood experiences, culture, and society—also influence creativity. Additionally, imagination fosters creativity, which in turn promotes the use of various thinking modes, including divergent, convergent, combinatorial, lateral, and associative thinking. By learning to continually challenge our biases and beliefs, critical thinking clears the way for imagination, while visual thinking allows us to access and apply the inner imagery of our minds.

Equipping students with visual thinking skills promotes cognitive flexibility in the iterative processes of reasoning and imagination during problem-solving. This involves understanding the neurophysiological processes underlying perception, perceptual mechanisms, and the use of mental imagery and analog methods. These skills are crucial not only in engineering but also across various disciplines, enhancing decision-making by improving comprehension of both qualitative and quantitative data. By providing students with a design methodology grounded in visual thinking, we enable them to approach communication and engineering with a deeper understanding of human perception and its interaction with technology.

This paper examines the integration of visual thinking pedagogy into secondary and postsecondary courses, exploring its connections with design, engineering, science, art, and communication. At the secondary level, it was incorporated into the senior engineering curriculum for four years, while at the undergraduate level, it was embedded in design courses and offered as a standalone course [9], [15]. The paper outlines the pedagogy, research methodology, and practical applications, illustrating how the integration of visual thinking into the curriculum enhances skills in reflective thinking, design, data visualization, and communication.

The research investigates how visual thinking can be taught and effectively integrated into transdisciplinary curricula, emphasizing the theoretical and practical value of manual, non-digital visual thinking strategies—such as sketching, drawing, writing, and physical modeling—in fostering conceptual understanding across disciplines. These analog practices are supported through students' use of a blank-page notebook, which serves as a central tool for exploration and reflection, enabling them to capture and connect their lived experiences both within and beyond the course. Focusing on pedagogical methods for teaching these strategies, the paper contributes to the growing body of research on their application in educational settings. Aimed at educators, researchers, and practitioners, it offers new insights into visual thinking education in the digital age.

Arguing that visual thinking is a crucial skill, particularly in engineering education, the paper presents its theoretical framework and application across diverse learning environments. It explores how students develop visual thinking through a structured pedagogy assessed via classwork, assignments, and activities such as critical reading, annotation, marginalia, ideation, metacognition, and design projects. These exercises engage various cognitive strategies, including spatial reasoning, memory recall, nonlinear thinking, and visual notetaking. Qualitative engagement metrics were gathered through a range of exercises and practices. These findings underscore the role of visual thinking in fostering deeper engagement and cognitive flexibility, offering a framework for its broader adoption in education.

Visual Thinking Pedagogy

The pedagogy of these courses, whether at the secondary or postsecondary level, is holistic and transdisciplinary, fostering intellectual, physical, and emotional growth while emphasizing self-perception and intrinsic motivation [9], [17]. This approach spans multiple fields, including the humanities, arts, sciences, design, communication, engineering, and architecture, promoting integrative learning. Humans have an extraordinary ability to shape their environment, creating objects and systems that carry meanings beyond their natural functions [18]. This capability is driven by cognitive skills such as visual thinking, abstraction, and goal-directed reasoning, which enable individuals to manipulate materials, design, and build [19]. Visual thinking is positioned as essential to engineering design capabilities, playing a pivotal role in fostering creativity through iterative cycles of observing, sketching, tactile engagement, and envisioning. These cycles promote the development and use of the mind's eye, which is crucial for effective design thinking [15].

This pedagogy is grounded in constructivist and experiential learning theories, emphasizing student-centered, neurobiological models of learning [20]–[27]. Relational methods explore how interpersonal dynamics and emotional responses shape student perceptions and engagement, fostering deeper connections within the learning process [28]. Reflective learning circles facilitate the sharing of work and dialogue, while the Socratic method encourages critical thinking. To promote meaningful interaction, class sizes are kept small, typically accommodating eight to twelve students, ensuring personalized attention and collaborative learning. This approach is informed by experience teaching visual thinking across various educational levels.

The methodology integrates inquiry-based and active learning with readings on visual thinking that combine text with images, data, and visual thinking practices [29]. Key texts include *Experience with Visual Thinking* by Robert McKim [30], *Engineering and the Mind's Eye* by Edward Ferguson [12], *Visual Thinking for Design* by Colin Ware [31], *Ways of Seeing* by John Berger [32], and several works by Edward Tufte, including *Visual Explanations*, *Envisioning Information*, and *The Visual Display of Quantitative Information* [33]–[35]. Student understanding of the visual system is enhanced through lectures and practical exercises.

Having established the pedagogical foundations of the course, the curriculum next delves into the cognitive aspects of learning, particularly focusing on the visual system and the role of visual thinking in fostering creativity and problem-solving. This shift in focus encourages students to apply the core principles of experiential learning through hands-on visual thinking exercises, allowing them to integrate theory with practice.

The curriculum is divided into three broad content areas, delivered through lectures, readings, and practical exercises. A unifying practice involves using a blank-page notebook, where students document their work and life experiences. This notebook serves as a versatile tool for capturing observations, writing, sketching, drawing, ideation, research, problem-solving, design, note-taking, prototyping, and collecting materials or objects of interest. It acts as a catalyst for ideation and design, promoting nonlinear thinking and integrating knowledge across disciplines and personal experiences. Students are encouraged to utilize this notebook and engage with visual thinking techniques, applying them across various disciplines and real-life situations, while critically examining their impact on the development of their overall cognitive processes.

Students also study the notebooks of historical visual thinkers, such as Leonardo da Vinci and Galileo [36], [37], learning how this methodology can facilitate the creative process. Through exercises in visual and nonlinear thinking, reflective writing, sketching, and visual note-taking, students develop a process for organizing their thoughts and ideas into a creative process. The notebook becomes an anchoring technique that offers structure amidst the inherent unpredictability of the creative process. Intrinsic motivation is fostered as students reflect in writing on their personal expectations and learning goals, connecting these reflections to their use of the notebook, course content, and their disciplinary interests.

The pedagogy integrates parallel tracks of student research and application, focusing on a comprehensive understanding of the visual system and visual thinking. Students investigate the visual system through biological, neuroscience, and psychological lenses, examining visual processing, perception, and pattern recognition [38]–[41]. They also explore visual thinking through the cognitive processing of sensory data, applying this knowledge in practical contexts [42]. Additionally, students analyze visual thinking from human evolutionary and interdisciplinary perspectives [43].

Students distinguish between the involuntary mechanisms of the visual system and deliberate cognitive processes. They examine how bottom-up sensory inputs, such as light and movement, interact with top-down processes involving memory, prior knowledge, and expectations to shape perception. Additionally, students explore how perceptual judgments are influenced by predictive mechanisms in the brain, which are refined through accumulated experience and memories [44]. Beginning in infancy, the brain starts constructing internal models of the environment by integrating multimodal sensory data [45]. As these models evolve, they form structured hierarchies of probabilistic predictions—Bayesian in nature—about future sensory input [44], [46]. In this framework, students learn that their brains constantly make educated guesses about what they see [44]. For instance, when they look at an object, their brain doesn't just process what's immediately visible but also predicts what might be hidden or out of view, based on past experiences. These predictions are based on patterns they have learned over time, making their perception faster and more efficient.

To ground their understanding of visual cognition in biology, students next study the anatomy and function of the visual system and its role in information processing. Students study the eye, photoreceptors, optic nerve, visual neural pathways, visual cortex, and higher-order processing areas, including the parietal and temporal lobes. The course covers how light reflects off objects, enters the eye, and undergoes neural processes as visual signals travel from the eye to the brain. These signals interact with sensory memory, contributing to the recognition of visual stimuli. With a foundation in how the brain processes visual information, students then explore how this sensory data is transformed into visual thinking. This transition from perception to cognition is key to understanding how we interpret, categorize, and use visual information in creative processes like design and problem-solving.

The curriculum emphasizes how conscious perception shapes how we interpret visual information. Students explore how the brain organizes and interprets raw visual data, such as object recognition, depth perception, motion detection, and color perception. The interaction between memory and perception is key to recognizing patterns, particularly in visual memory and how prior experiences influence the interpretation of visual stimuli.

Students explore the role of memory in visual processing and thinking, with a focus on sensory, short-term, and long-term memory. They examine both implicit and explicit forms, emphasizing how procedural memory enables the automatic execution of tasks such as drawing, problem-solving, and design. This unconscious processing of learned motor skills allows students to redirect cognitive resources toward more complex and creative aspects of visual thinking, such as ideation, abstraction, and conceptual reasoning.

Students explore two types of explicit memory: semantic and episodic. Semantic memory is responsible for storing general knowledge, including facts, concepts, and meanings. In the visual system, it plays a key role in processes such as object recognition, pattern identification, and abstract categorization. Within the context of visual thinking, semantic memory contributes to interpreting visual information, recognizing symbolic structures, and supporting reasoning grounded in conceptual and visual knowledge.

Episodic memory, on the other hand, involves the recall of past events, including details such as locations, visual experiences, actions, and interactions. Its role in the visual system is explored through memory-based perception, contextualization, and the reconstruction of visual scenes, influenced by both bottom-up and top-down processes. In visual thinking, episodic memory aids in mental imagery, imagination, creative visualization, and problem-solving based on memories of past visual experiences. Both types of memory are crucial in enhancing visual cognition and supporting various forms of thinking, including associative, critical, and scientific reasoning.

Building on the concept of memory, students next explore the role of pattern recognition, a process in which sensory input is matched with stored knowledge or past experiences. This process is essential for recognizing symbols, structures, and regularities in the environment. Visual memory aids in interpreting patterns, contributing to facial and object recognition, Gestalt principles, and contextual processing. The curriculum also explores how brain chemistry influences neural connections in response to visual stimuli, which can trigger a dopamine response linked to screen technology addiction.

As students learn about the visual system, they engage in visual thinking through reading and practicing multisensory integration. Visual thinking, a flexible cognitive process, involves using mental images, memory, and spatial relationships to enhance creativity, problem-solving, and decision-making. Students learn how visual thinking integrates with other cognitive processes, such as interpretation, communication, and abstraction, and practice key operations like patterning and synthesis.

Students explore the nature of visual thinking, its influences, and how it manifests. They practice key visual thinking operations like rotation, abstraction, and synthesis, at both conscious and unconscious levels. Through metacognitive exercises, they learn how visual thinking integrates with other cognitive modes, such as verbal, analytical, causal, scientific, and critical thinking. Students apply this integration in problem-solving exercises, promoting flexible thinking. Additionally, they investigate the role of visual thinking in scientific inquiry, using it alongside critical thinking, intuition, reasoning, and design thinking.

To encourage tactile engagement, the course provides a wide variety of materials and tools, including pens, sketchpads, paint, paper, cardboard, clay, wood, wire, glue, tape, and scissors—tools that connect thought to hand. While the course primarily relies on analog practices to foster cognitive development [47], digital tools were used selectively for some student presentations. Students also develop critical reading skills through analog annotation, marginalia, and written responses. These practices connect comprehension to active notation and diagramming, fostering analytical and reflective writing.

The curriculum emphasizes reflective, active, and experiential learning, with a strong focus on student self-assessment and agency. Students’ feedback is integrated into mentoring sessions, promoting self-agency in learning and fostering a kind and caring mentoring environment. Pedagogical practices, such as individual student conferences, offer valuable opportunities for assessing knowledge integration and behavioral strategy improvement.

Research Methodology

This study aims to evaluate the effectiveness of incorporating explicit teaching and practice of visual thinking into secondary and postsecondary education, identify relevant analog practices, and assess students' responses to its inclusion. It investigates how visual thinking, as a critical mode of thinking in design, can be integrated into these educational levels, particularly in engineering programs and honors courses.

The research adopts a holistic, transdisciplinary approach to examine the relationships between visual thinking, creativity, and problem-solving. Key areas of focus include: the impact of understanding the biology and neuroscience of the visual system on visual thinking and related practices; the influence of analog practices on visual thinking; and the identification of other practices that support the development of visual cognition.

This study explores several key questions related to the integration of visual thinking into higher education. For instance, how does an understanding of the biology and neuroscience of the visual system affect visual thinking, problem-solving, and creativity? Furthermore, what role do analog practices, such as the use of blank-page notebooks, play in influencing visual thinking? Another area of interest is whether exposure to transdisciplinary knowledge enhances visual thinking, and how visual thinking can influence creativity and problem-solving in engineering design. Additionally, the study seeks to understand how visual annotation and marginalia contribute to students' comprehension and writing processes, as well as how visual thinking impacts communication practices. Finally, the research considers what other practices best support the development of visual thinking.

To investigate these questions, a range of qualitative methods were used [48], including classroom observations, student work artifacts, conferences, interviews, and surveys. Survey data were collected through the university’s course feedback system, which gathers insights to improve teaching and learning. Longitudinal secondary data were also collected post-graduation through follow-up interviews to explore students’ longer-term reflections on their learning experiences.

Subjective and qualitative findings were analyzed using comparative and contextual approaches to examine interactions between relational dynamics and pedagogical strategies. These analyses were aligned with the research questions and aimed to generate theoretical insights into transdisciplinary relational teaching and its impact on students' cognitive and emotional development.

Given the personal nature of the subject matter, qualitative methods—particularly interviews and group dialogues—were essential for capturing participants’ lived experiences, emotional responses, and motivations. Responses were categorized within transdisciplinary knowledge frameworks, linked to pedagogical outcomes, and examined for trends and patterns using theory-building approaches. Causality was considered only in the context of unique interactions within the study.

By centering student experience, this methodology supports iterative cycles of reflection and refinement in engineering pedagogy. The findings offer practical insights into how learning visual thinking can aid in self-reflective practices, design thinking, and relational awareness in engineering education.

Application

The integration of a visual thinking educational methodology has been implemented across various educational levels, including eight senior-level, year-long secondary engineering courses, five postsecondary undergraduate interdisciplinary engineering courses, and five transdisciplinary postsecondary honors courses. Elements of this pedagogy have also been incorporated into other engineering courses as the methodology continues to evolve [9].

At the start of the course, students are introduced to examples of paper notebooks used across disciplines, including the arts, engineering, science, writing, architecture, and design. They examine transdisciplinary notebooks from practitioners who combine multiple fields—such as art, engineering, and writing—using visual thinking techniques. These examples encourage students to explore nonlinear, iterative, associative, and abstract thinking, demonstrating how combining words, images, and data can lead to deeper insights and the cross-pollination of ideas. Students observe how seemingly chaotic ideas from diverse life experiences can evolve into cohesive representations, aiding idea generation and communication across disciplines such as design, engineering, art, and architecture.

Central to this approach is the use of blank-page notebooks, which students use to document their thoughts, reflections, sketches, ideas, and experiences both inside and outside the classroom. This tool encourages open-ended exploration, nonlinear thinking, and creativity, promoting both cognitive and emotional expression. By engaging in reflective writing and sketching, students deepen their understanding of design thinking and develop critical skills for creative problem-solving, self-awareness, and emotional intelligence.

A variety of pedagogical tools were employed, including reflection circles, dialogues, mentoring, individual conferences, and a digital-free classroom environment emphasizing analog practices. These practices, combined with the consistent use of analog tools, promote focus, sustained attention, and intrinsic motivation. The course methodology emphasizes sketching, drawing, ideation, and iterative processes to refine ideas and solutions, complemented by visual note-taking to encourage creative development. These activities, paired with presentations incorporating visual imagery and oral communication, build effective communication skills. Exercises in creating visual displays of evidence strengthen analytical and persuasive abilities, while seminar dialogues foster collaborative learning. Individual conferences provide opportunities for personalized feedback and growth. Together, these practices not only promote content knowledge but also critical, causal, and analytical thinking, as well as language, visual, and nonlinear thinking, fostering a rich and engaging learning environment.

To integrate visual and language-based thinking, students engage in critical reading with paper copies of assigned texts, using visual annotation and marginalia as tools for reflective and analytical writing. This process helps students identify the author's thesis and main points, assess the veracity of claims, and relate the material to prior knowledge. Writing notes in the margins promotes critical thinking and curiosity, while concept maps and symbols like arrows and diagrams deepen understanding.

Lectures and readings on the biology and neuroscience of the visual system provide a scientific foundation for visual thinking. Additional exercises explore cognitive flexibility and various reasoning processes. Students then apply these theories through activities, seminar dialogues, and exercises that integrate visual, language, and analytical skills. As part of this, they transform their marginalia into an analytical paragraph, enhancing cognitive flexibility and reinforcing the integration of visual and language-based thinking. The encompassing notebook continues to serve as a space for recording reflections, summaries, and analyses, further strengthening students' ability to synthesize and apply knowledge.

At the beginning of the course, students reflect in their notebooks on their expectations for developing visual thinking skills, what they hope to learn, how it might impact their cognitive abilities, and its relevance to their field of study. These reflections inform the course's core components, which focus on annotation and marginalia in critical reading, cognitive operations and flexibility, understanding the neurological processes of visual systems, and cultivating visual thinking skills.

The blank-page notebook is a central artifact of the course, documenting students' experiments, practices with visual thinking, and lived experiences. It contains a variety of mixed-media content—from writing and sketching to dissected plants, flowers, and printed materials—blending scientific, humanities, literature, artistic, design, and experiential elements. This "catch-all" repository offers a multidimensional perspective on knowledge, fostering connections across disciplines. Additionally, the notebook serves as a reflective tool, tracking students' intellectual and creative development while illustrating how visual thinking shapes their thought processes, flexibility in modes of thinking, and the evolution of ideas. In this framework, students are encouraged to adopt the blank-page notebook methodology, integrating visual thinking strategies throughout their academic and personal experiences. These techniques are applied across various contexts, promoting deeper reflection on how they shape and enhance cognitive growth.

Targeted exercises, such as metacognitive problem-solving, promote awareness of cognitive processes and enhance flexibility in applying diverse thinking strategies. Moreover, lectures, readings, and practices in visual thinking support the development of internal mental imagery, or the "mind's eye," fostering skills in pattern recognition and problem-solving.

A metacognition exercise, based on the monk-on-the-mountain problem, asks students to use their notebooks to record, side by side, both their thought process for solving the problem and the actual steps they are taking to solve it [49]. They are prompted to reflect on and document how their cognition (thought process) is attempting to solve the task—how their thoughts are represented to them—while simultaneously working to solve the problem. Figure 1 provides an example, showcasing the results produced during one such engagement.

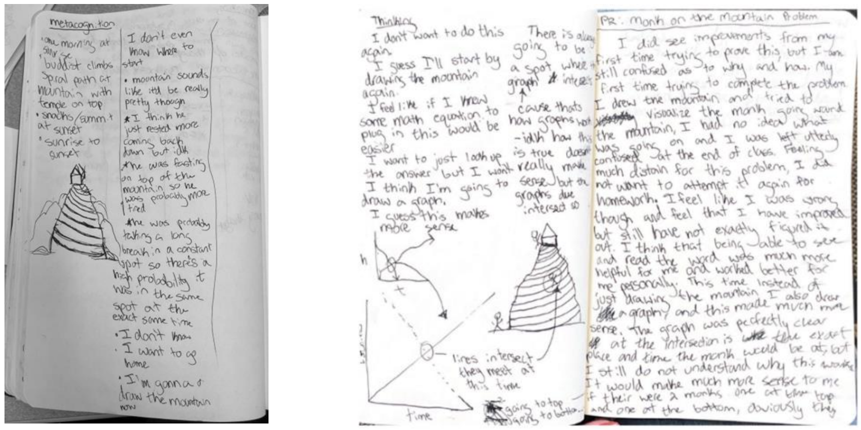

Figure 1. Example of student's metacognitive reflection in problem-solving

This exercise promotes awareness among students of their thought processes and learning strategies. Through this task, students gain insight into the types of thinking they engage in. For some, visual thinking is most prominent, while for others, the process may be more language-based, analytical, or a combination of these. Ultimately, students learn about the power of combining visual and language-based thinking, as well as problem-solving operations such as filtering with language and superimposition in visualization.

There is a particular emphasis on individual thinking modes and the fluid transition between them, highlighting critical, causal, associative, and visual thinking. Visual thinking, closely linked with various attributes of engineering design capabilities, plays a pivotal role in fostering creativity. Through iterative cycles of observation, sketching, and envisioning, it facilitates the development and use of the mind's eye, which is essential in design thinking. Through these projects, students gain proficiency in utilizing the mind's eye, conceptualization, hand-eye coordination, sketching, drawing, building, evaluation, feedback, iteration, and working with materials and tools.

One of these projects is a 'pierced holes' exercise, where students work individually and iteratively, transitioning through different sensory and cognitive stages—auditory, internal mental imagery, sketching, tactile, and bodily. The objective of the exercise is to design an object that can block all light while passing separately through a circle, square, and triangular hole. The square can be circumscribed around both a circle and an isosceles triangle, with the circle touching all four sides of the square. The isosceles triangle, with its top vertex touching the top side of the square, has its base aligned with one side of the square, making the base equal in length to the side of the square.

The exercise involves students moving between different modes of thinking and tools—using the mind's eye, sketching, and working with materials such as scissors, tape, paper, and cardboard, before culminating in the use of a template and clay. This iterative process allows most students to solve the problem within the allotted time, reinforcing the connection between reason, imagination, curiosity, creativity, empathy, design, and technology. Figure 2 provides an example, showcasing the ideation artifacts created during one such engagement.

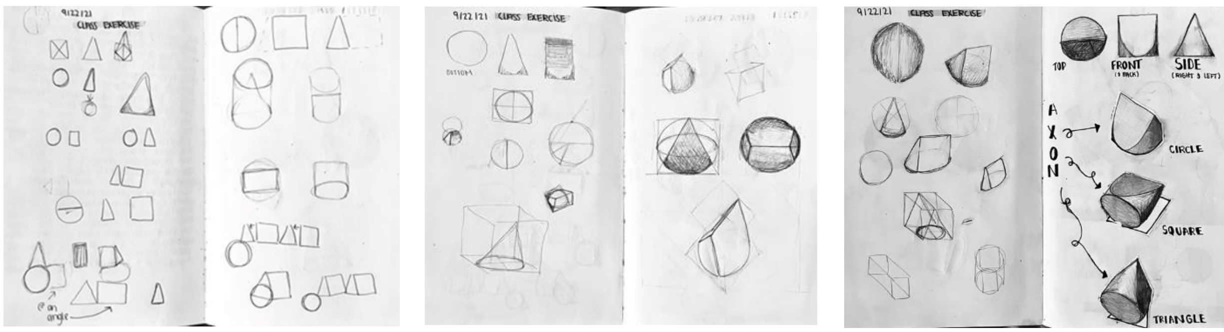

Figure 2. Example of student ideation engagement in the pierced holes exercise

Some students become frustrated when they cannot find a solution through mental visualization, sketching, or working with carboard which fosters motivating doubt. However, when working with clay, they unconsciously shift to embodied and bodily thinking, channeling their emotional energy into shaping the material. They squeeze the clay through the holes repeatedly until the right form emerges. This exercise cultivates flexibility in students' modes of thought, enabling them to transition between different thinking modes and become more creative and adaptable problem-solvers.

To foster visual thinking, engage the mind's eye, and strengthen connections to episodic memory, students begin by reading a narrative titled *Biplane Visualization Takes Flight* [50], which recounts M. J. Povinelli's childhood experience of participating in an elementary school science fair, where he designed a levered amphitheater for biplanes. The narrative explores creative, visual, critical, causal, scientific, and design thinking, illustrating their interplay with reasoning, memory, and emotions. It also portrays the author's journey of overcoming both technical and interpersonal challenges. The story integrates text, photographs, sketches, and drawings, providing a multidimensional perspective.

Building on this, students participate in a series of exercises aimed at reflecting on their own experiences with design, building, and testing. They begin by compiling a list of personal projects undertaken throughout their life. From this list, they select the earliest and most impactful project. Students then create sketches and drawings of their chosen project, including perspective and isometric views from memory.

Next, they write a detailed account of the steps they took to build their project, ensuring the description is vivid enough for a reader to construct a mental image of the outcome. To achieve this, students are encouraged to use their sketches and drawings to guide their writing. They are asked to test the clarity of their description by having someone read it and compare it to their drawings. The narrative also includes reflections on the challenges they faced during the project.

Finally, students engage in a series of reflective writing prompts that examine the broader impact of their project. They consider questions such as how this experience and its memory influenced their connection to other design projects, personal growth, or interests, as well as what types of thinking—visual, scientific, or design—were involved in the process.

This exercise not only reinforces connections between visual and language modalities but also deepens their understanding of the cognitive and emotional dimensions of the design process.

Students then present their work to the class, sharing their sketches, written descriptions, and reflections on the impact and thought processes involved in their project. Figure 3 illustrates an example, featuring the sketches and writing produced during one such engagement.

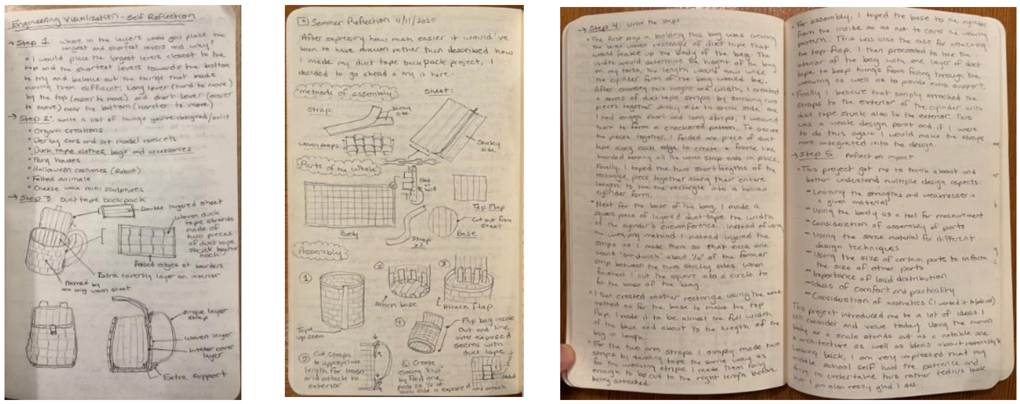

Figure 3. Student sketches and reflections on memory of personal design project

Students explore how human observations of nature have historically stimulated visual thinking, pattern recognition, and the development of principles in design, aesthetics, causality, art, writing, and tool creation. Activities designed to stimulate visual thinking through a cycle of seeing, drawing, and imagining include examining nature, collecting and studying plants through dissections of milkweed and burdock burs, observing ecological systems, and documenting an organism's life cycle and environmental interactions in detail. Figure 4 illustrates examples of these exercises from students' notebooks.

Figure 4. Examples of students’ observations and interactions with nature

As a tool for visual thinking, the blank-page notebook promotes freedom and creativity in how information is represented. It supports critical, associative, and organizational thinking, aligning with scientific processes by integrating language, causal reasoning, intuition, and inductive approaches. Through cycles of seeing, imagining, and drawing, students explore concepts and connections, while engaging with mental operations central to visual thinking, such as pattern recognition, memory retrieval, categorization, and spatial reasoning [30]. Visual thinking is explored at both conscious (cognitive) and unconscious (dream imagery) levels.

Students use the notebook to visually represent abstract concepts through diagrams, charts, and mind maps, simplifying complex ideas and helping connect new material with prior knowledge. They capture ideas in real time during lectures or study sessions with pictures, symbols, and shorthand, enhancing retention, abstract thinking, and problem-solving. Additionally, students organize conceptual relationships using flowcharts, timelines, and Venn diagrams, clarifying abstract connections. The notebook also serves as a repository for research, quotes, and ideas, deepening understanding by consolidating key concepts in one place.

Students create concept and mind maps to represent ideas nonlinearly, fostering connections between related concepts more effectively than traditional linear notes. Visual elements, such as color-coded drawings and annotations, aid memory and cognitive recall. Reflection and journaling—key components of transformational learning—combine words, symbols, sketches, and research to track thought development, build a personal visual vocabulary, and connect visual expression with conceptual understanding. This practice also encourages creating visual analogies, linking abstract concepts to familiar scenarios. The shift to nonlinear and visual notetaking, facilitated by a blank-page notebook, is illustrated in Figure 5.

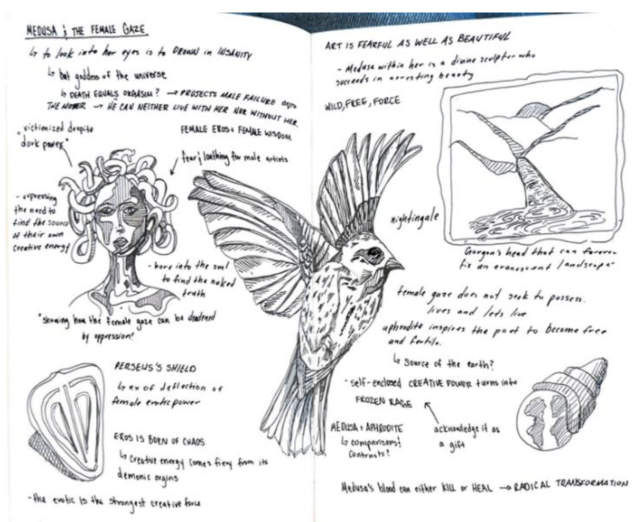

Figure 5. Examples of student nonlinear and visual notetaking in response to course reading

Doodling, a form of unstructured exercise, encourages freeform thinking and creative exploration, sparking insights and facilitating abstract connections. The da Vinci device—helping students develop their internal imagery and 'mind's eye'—further nurtures imagination and creativity.

Through observation and "intense seeing," students explore how scientific thinking connects to broader ideas and practices, including art and everyday decision-making. They engage in a visual thinking and scientific reasoning exercise based on Galileo's daily observational drawings from January 7th through 11th in 1610, where he recorded objects around Jupiter. Students use various thinking modes, intuition, and reasoning to hypothesize what the objects might be and why. They then analyze how Galileo combined images and words in his notebook to reason, test, and provide evidence for his hypothesis. Through this exercise, they learn about the cyclical process of scientific thinking, which integrates visual, critical, causal, intuitive, and inductive reasoning. This process demonstrates its relevance as a universal cognitive approach. The cyclical nature of scientific thinking, as illustrated in Figures 6, emphasizes the integration of these reasoning modes, highlighting their applicability not only to visual and scientific thinking but across disciplines.

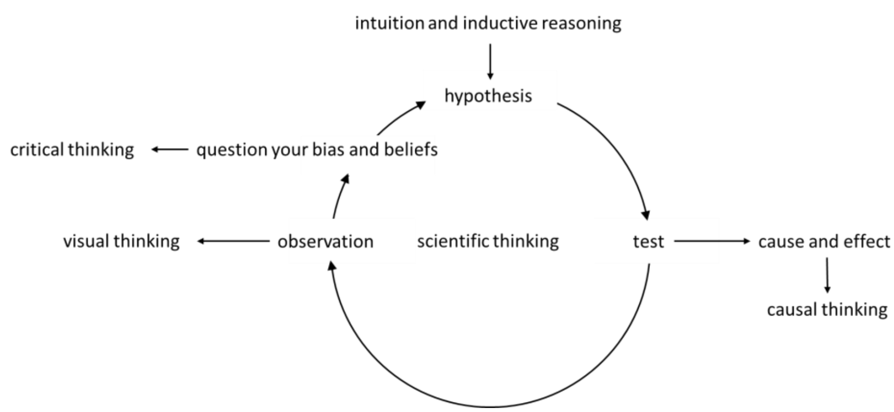

Figure 6. Relationship between visual and scientific thinking

The spiraling, cyclical process of scientific thinking, depicted in Figure 7, emphasizes to students the importance of subjecting our beliefs and biases about objective reality to critical thinking, highlighting its relevance to learning.

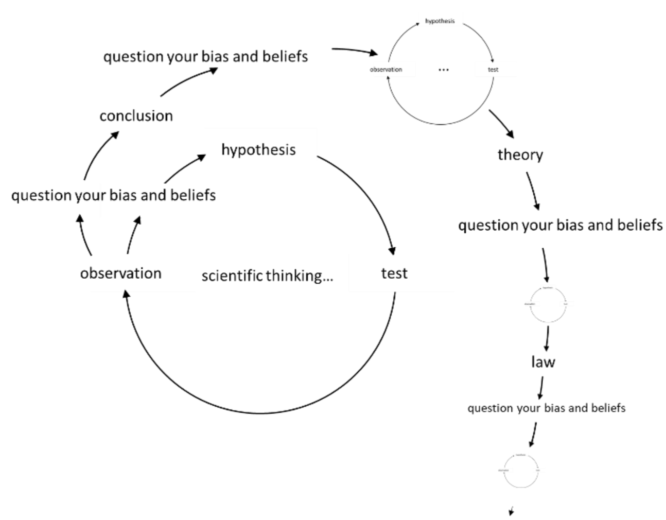

Figure 7. Spiraling, cyclical process of scientific thinking and its role in critical evaluation

By documenting experimental steps—such as expectations, observations, reflection, and practices—students engage in systematic scientific thinking while cultivating habits of observation, visual and critical thinking, and careful reasoning. Reflecting on their methods helps them assess effectiveness of their visual thinking development, identify areas for improvement, and refine their approaches. Over time, the notebook becomes an invaluable resource for thoughts, reflections, ideations, mind and concept maps, practices, tools, habit formation and continued learning.

Results and Dialogue

The framework guiding this investigation positions visual thinking as central—rather than peripheral—to the study, practice, and pedagogy of design, specifically within engineering. This emphasis on developing visual thinking both as a deterministic system and as a cognitive skill is reflected in students' diverse responses. Some students openly express challenges in forming mental images, while others mention their fear of failure when attempting to express ideas visually, whether through sketching, drawing, or ideation.

Across both secondary and postsecondary reflections, the results suggest that offering learning content focused on visual perception and thinking provides actionable knowledge that enhances cognitive abilities in various areas of students' lives. Previous research indicates that secondary students taught visual thinking continue to value these skills throughout their college education [15], and both secondary graduates and postsecondary students recognize its valuable role in design thinking [9].

The study also revealed the promising impact of a digital-free classroom, with a focus on analog practices, particularly in reflective practices, self-awareness, cognitive and emotional engagement, and design thinking. Additionally, the study assessed the impact of critical reading techniques—such as visual annotation and marginalia—on writing, as well as exercises in metacognition, creative thinking, memory, and scientific reasoning. The analysis explored how visual perception, informed by biological and neurological perspectives, intersects with analog practices to enhance visual thinking in education. Specifically, it examined six core pedagogical questions.

Is visual thinking viewed as useful educational content by students?

Students consistently recognized the transformative impact of visual thinking on their learning. Many reported enhanced creativity and problem-solving skills, with one stating, "This class helped me develop visual thinking skills, allowing me to think outside the box and think of solutions I normally wouldn't think of." Students also valued its broader significance, such as learning "how it differs from other types of thinking such as linguistics." Another student shared, "Learning why visual thinking is important…and how to implement it was equally essential."

Students also recognized visual thinking as a transferable skill. One remarked, "I started drawing out points from other courses, making my notes more legible and interactive and challenging me to interact with my work more." Its interdisciplinary value was evident, as an architecture student noted its relevance for design critique and "understanding the responses it could receive from others." Similarly, an engineering student highlighted the gaps in their curriculum and how this course addressed them, stating, "In my experience, engineering curricula have not exposed me to ways to develop and fine-tune visual thinking skills. This course showed me how visual thinking can enhance communication, drawing ability, and conceptual strategies for innovation."

The course fostered self-awareness and the practical use of memory. One student reflected, "I've become more aware of my thinking and started applying class concepts to solve everyday problems like using episodic memory to solve practical problems." Overall, students advocated for the broader integration of visual thinking in education, with one concluding, "Visual thinking should be applied across more classes to reverse its undervaluation in today's education system." This suggests that visual thinking is a vital skill for academic and professional growth, transforming how students learn, solve problems, and engage with their fields.

How does an understanding of the biology and neuroscience of the visual system influence visual thinking, particularly in problem-solving and creativity?

Understanding the biology and neuroscience of the visual system enhances visual thinking by explaining how the brain processes and utilizes visual information. This course emphasized the connection between biological mechanisms, cognitive processes, and practical applications, demonstrating that visual thinking skills can be cultivated. Students stated that this “context helped them understand how I could improve my visual thinking” and “it’s easier to apply to design if you know how the visual system works.” Another student stated, “understanding the bottom-up and top-down processing in the brain and aspects of how a baby develops their visual perception and thinking allowed me to see everything in a new light and better foster my own visual thinking.” One student observed, “The exercises in visual thinking" taught them "how to use the tools of our brain to visualize certain places or objects, stationary or moving," and improved "our visual thinking and imagination.

The course also emphasized how the brain processes visual information, helping students create visuals aligned with cognitive processes such as color, pop-out effects, and pattern recognition. As one engineering student explained, knowing “what kinds of visual information the brain can process efficiently, as well as the timing and sequencing of visual operations…can make or break your design and determine how quickly/thoroughly information is gathered from whatever visual display is being constructed."

This knowledge proved particularly valuable for students learning how to effectively communicate their ideas in fields like engineering, architecture, the humanities, and the sciences. One student reflected, "Understanding how the brain processes visuals [helped them] create more effective communications." An architecture student added, “The 'Pop-out effect' and understanding how to use color helped me understand why something did or did not work graphically…since 90% of our work is solely diagrams."

Students remarked on learning that the visual system’s efficiency relies on memory and subjective forces, which shape perception. As one student shared, "The visual system is biologically hardwired for efficiency and requires the brain to work with it to fill in perceptual gaps. These gaps draw upon individual memories, emotions, and other subjective forces, making reality quite subjective.” The course addressed the dual-edged nature of pattern recognition, which can introduce biases. One student said, "Pattern recognition works in finding information quicker but can also create bias. Critical thinking helps us examine these biases and identify when to use them appropriately."

Historical perspectives, like Ice Age ornamentation and tools, provided context for understanding the roots of visual thinking. One student remarked, studying the evolution of Homo sapiens visual representation is key to understanding “modern visual thinking skills." Learning the neuroscience and biology of visual thinking made students more reflective and precise, as one summarized, "I’ve become more complex and in-depth, aware of visual thinking processes." This integration of science, philosophy, and practice deepened students’ understanding of visual thinking’s academic and professional applications.

How do analog practices, such as blank-page paper notebooks, influence visual thinking?

Analog practices, such as using notebooks and sketching, enhance visual thinking by fostering creativity, improving problem-solving, and connecting thought with expression. As one student responded, “Using the notebook to freely do reading and class exercises and freely write notes was very helpful in applying what we learned about visual thinking in relationship with modes of thinking and in design.” These practices allow ideas to flow more freely and flexibly. Many students found that physical drawing linked their hand and mind, boosting creativity and ideation. One student remarked, “I found a connection between hand and mind that is far more valuable to me than simply learning how to draw technically. “Analog practices also encourage "thinking on paper," helping transfer ideas to a tangible medium for clarity and iterative exploration. As one student said, its “more efficient to transfer my thoughts and ideas onto paper…than visualizing everything in my head."

The course helped students overcome perfectionism and overthinking by encouraging them to "think on paper." One student shared, “sketching has given me the ability to look back through my notebooks to find inspiration or thoughts relevant to new ideas.” Notebooks also served as repositories for diverse thoughts, helping students break free from structured patterns and biases. My notebook “captured a lot of different perspectives and helped me break out of structured patterns, beliefs, and biases," one student noted. The freedom to combine visuals and text in notebooks promoted holistic thinking, with one student reflecting, “lineless pages gave me the freedom to explore effective ways of combining drawings with text.”

The unstructured nature of analog practices promoted creativity and self-reflection. One student said, "The freedom to explore in our notebooks encouraged me to think creatively and search for answers to questions I came up with.” Detailed observation exercises, like drawing objects from different angles, sharpened visual focus. A student shared, "Drawing…and comparing sketches helped me improve my accuracy with focused attention and imagination." Analog practices also taught students to document their creative processes systematically, making the skills transferable. “Documenting my creative process during studio projects is integral to design. I realized I could apply this method outside my studio class, making it applicable in my everyday life," one student remarked.

Secondary students who learned visual thinking continued to value it in college. Among 58 students who took an engineering course with visual thinking pedagogy, 39 reported valuing visual thinking and its attributes including the blank-page notebook method. Students highlighted its value for “visual notetaking,” as “a place to organize my thoughts,” and as “a method to help my thinking on the course work.” One engineering student describing it as “a powerful tool for their thinking practice.” A first-year engineering student shared, "I realized the value of the blank-page method I was taught when I saw my peers' lined notebooks, which lacked the same depth. My notebook was filled with words, diagrams, and arrows, capturing information in a way that linear notetaking couldn't." They added, "I realized the blank-page method allowed my brain to capture content in a way that linear notetaking couldn't. It helped me think differently." Another student added, "The blank-page method has been so beneficial—I would never return to a regular notebook."

Students often recognized the broader benefits of visual thinking, such as empathy and creativity. One engineering student remarked, “I’ve learned how to become a strong visual thinker” and “how to incorporate empathy into everything I do.” Another shared, “This class inspired me to buy my own personal notebook so that I can record and sketch as I please, to further stimulate my creativity.”

The use of the notebook to foster the iterative process of ideation helped students refine ideas, fostering critical and creative thinking. One student noted, "I focus more on depicting thoughts visually rather than relying solely on words." While some recognized the shift to digital methods, they saw value in combining both analog and digital tools. As one student said, "Using both methods at different stages enhances creativity and design." Overall, analog practices lay a foundation for visual thinking, emphasizing exploration, reflection, and integration of diverse thinking modes, especially in creative and design-focused disciplines. Additionally, both the use of a analog notebook documenting class activities and journaling techniques and helped students better process material and integrate their learning, with one stating, “Setting up a notebook similar to the one used for this class will help me examine architecture more on my own.”

Does exposure to practices from different disciplines enhance visual thinking?

Exposure to practices across different disciplines broadened students’ understanding of visual thinking’s versatility and relevance. A student remarked, “Hearing from others with diverse academic backgrounds helped me rethink approaches I might not have considered on my own.” Collaborative learning further enriched the experience, with students gaining new perspectives from peers in different disciplines. As one shared, “Sharing ideas in this class was very important because we were all able to hear everyone’s different points of view, and by sharing some background information [and majors], we were able to see why they think the way they do.” Peer dialogues also played a significant role in hearing “peer perspectives,” as one student stated, “I was excited to learn more about how people outside of my major think; it caused me to think about and helped me question topics I never have before.” Another explained how interdisciplinary exposure informed their approach to representation: “Listening to my classmates with different backgrounds, I learned that visual thinking is applicable to many other fields, from biology to architecture." Another remarked, "This course challenged me to see the world with fresh eyes. I was able to apply what I learned to other areas of study."

How does visual thinking influence creativity and problem-solving in engineering design?

The integration of visual thinking into engineering education significantly enhanced students' design abilities, creativity, and communication skills. Reflecting on their experiences, students consistently cited how visual thinking enhanced their problem-solving approaches, creativity, and overall engineering design process. One of the most frequently mentioned benefits was the ability to translate abstract ideas into tangible representations. As one student noted, "Visual thinking will help me be a better engineer, and I will use this skill in future work I do, whether it be inventions or improving on current technology."

A key theme was visual thinking's role in fostering creativity and ideation. One student noted, "I gained insight into fostering creativity, understanding people, and implementing my design ideas." Another observed, "Through the use of creativity, visual thinking, and the design process, engineering innovative products becomes increasingly effective." Further, a student emphasized, "Visual thinking promotes ideation and iteration in design." The ability to sketch and visualize ideas enabled students to refine designs and make adjustments before implementation. One student explained, "Visual thinking will help me…visualize what I want and how it will work so I can put those ideas to paper." Students also reported that the class "helped me develop my visual thinking skills, think outside the box, and think of solutions I normally wouldn't think of."

Many students also highlighted the connection between visual thinking and empathy, considering both vital for approaches to engineering design. One student explained, "Visual thinking, creativity, and empathy are important skills for an engineer to possess in order to use a design process that drives inventions, innovations, and technological advancements in society."

Improved communication was another key impact of visual thinking, especially in presenting complex ideas and data. A student remarked, "Getting better at visual thinking helps me make my mathematical skills better and helps me visualize engineering problems better. Creating effective infographics and presenting data effectively is a big deal in engineering as you have to frequently present your work to others who may or may not be familiar with it." The skill of visual representation, including sketching and creating infographics, allowed students to present ideas more clearly and persuasively in multidisciplinary environments.

Finally, many students emphasized the importance of sketching in the early design stages. As one student noted, sketching was crucial "to discover the concept of my design." Students found that sketching helped refine design ideas, laying the groundwork for more detailed engineering work. In conclusion, students' experiences highlight that visual thinking enhances creativity, ideation, and is essential for effective engineering design.

How do visual annotation and marginalia support students' comprehension and writing processes?

Students expressed that engaging with texts through visual annotation and marginalia not only enhanced their comprehension of the material but also transformed their writing practices. Many found these techniques valuable in connecting reading to the writing processes, allowing for deeper reflection and articulation of ideas. One student shared its enduring value, saying, “The ability to link reading, annotating, and writing improved my critical thinking and understanding of texts, making this a skill I’ll carry forward.” Another noted, visually “annotating readings helped me articulate my thoughts before writing, making the process more reflective and structured.” Another reflected on how these methods supported their ability to visualize and organize ideas: "In writing, I am now thinking more visually, bouncing between verbal and visual, even though it may be just putting thoughts into words."

The practice of annotation, particularly with a focus on identifying the author's thesis and main points, emerged as a key tool for many students: "Annotating the readings and adding marginalia with a focus on finding the author's thesis and main points helps me express my thoughts before I write." Several students also acknowledged the role of annotation and marginalia in fostering critical engagement with texts. This was particularly evident in responses connecting readings to disciplines such as architecture and visual thinking: "This reading gave lots of good advice specifically on making diagrams, which is relevant to what I need to do for architecture."

The interactive nature of the course, which combined reading, annotation, and class dialogues, further reinforced these practices: "Competing activities from the readings and sharing/discussing them in class was most effective. The readings and seminars were the most effective for me. They allowed all of us to have a dialogue about the reading and complete activities that furthered our knowledge even more." These reflections suggest that analog visual annotation and marginalia not only foster a more profound understanding of texts but also cultivate habits of mind that inform and enhance writing practices, encouraging students to see academic writing as an iterative and integrated process. As a student reflected on the benefit of the approach in the course, we integrated “what we had learned about analytical reading and writing and combined it with visual thinking and drawing to create a holistic understanding of thought. Through writing the final paper, we can showcase what we have learned and effectively demonstrate our understanding.”

How does visual thinking influence communication practices?

Communication practices developed through collaborative and seminar-led dialogues and presentations strengthened students’ visual and verbal communication abilities. Students highlighted how the course enhanced their visual thinking and communication skills, particularly in presenting ideas clearly. One noted, "I’ve learned to be a strong visual thinker, which will help me communicate efficiently." Another added that visual thinking improved communication in engineering, making ideas easier to understand. Another student remarked, “I learned how to make my PowerPoint presentations more understandable without using chart junk and too many words.” Students also highlighted the practical skills gained, such as presenting data effectively and organizing complex concepts. One student shared, “I applied the lessons to a professional presentation, trying to make it more appealing and informative.”

The student-led seminar format was especially impactful. One student reflected, “Leading classes and exercises proved to be the part that most directly elevated my skills as a presenter and critical thinker." The course's collaborative structure fostered intellectually stimulating dialogues, allowing students to refine their presentation and critical thinking abilities. One student found the dialogues valuable, saying, "I really enjoyed hearing other perspectives... the class dialogues were the best part of this class." These interactions also helped build peer relationships and boost confidence. "By the second seminar, I felt much more comfortable leading class dialogues," another student shared, highlighting the development of their public speaking skills. Active participation played a crucial role in the learning process, with students noting that it fostered engagement and self-directed learning. One student remarked, "After this class, I've become more self-directed and more open to sharing my ideas [visually]."

What additional practices best support the development of visual thinking?

Hands-on activities and reflective practices were pivotal in strengthening students' visual thinking. Drawing the visualized internal mechanical components and then taking apart a mechanical toy alligator deepened one student's understanding of the mind's eye in engineering: "[It] helped me better understand how to create images in my head, by drawing what I had and [then] looking at it in person, figuring out what was missing and what the system needed in order to function properly." Several students remarked on the power of observing nature as one student stated, "when I dissected the milkweed pod, I discovered a whole world I had not seen before that could inform both my imagination and drawing." Relaxed attention also played a critical role in fostering creativity and engagement. One student noted, "By relaxing irrelevant tension, [I could focus my] full energy and attention on the task. The strategies in fear-reduction through relaxed attention were incredibly valuable."

several students noted the increased ability in divergent thinking with one student noting how "many solutions could be better than one." Several students also noted that visual thinking practices helped them develop a more critical awareness of their own work and the work of others. One student described this as transformative, explaining, "Our knowledge of how we see, perceive, and hold visual attention allowed me to look more critically at my work. Rather than being unconvinced by a drawing, I can explain why and find new means of representation." This critical awareness extended beyond design into fields like data visualization, where students connected course practices to real-world applications such as creating effective infographics or communicating quantitative data. As one student observed, "This class was not just about how we see, how we can use drawing, and what makes visuals successful. We spent a lot of time diving into how we experience thinking, mindfulness, journaling, and analyzing dreams."

Class Exercises in Metacognition, Pierced Holes, Memory Recall, and Scientific Thinking

Students' reflections on the metacognition exercises revealed a heightened awareness of their cognitive processes. They remarked on how the 'monk on the mountain' exercise demonstrated that becoming aware of how thoughts are represented in their consciousness was useful for transitioning to different modes of thinking. One student shared how the course helped them recognize the importance of being conscious of their problem-solving approach, noting: "Now I am much more conscious of how exactly my brain goes about solving problems. It's helped me see patterns in myself and approach problems from different angles." Another student explained how involving auditory thinking and visual sketching deepened their understanding of the power of diverse cognitive processes. This was echoed by another student, who emphasized how "metacognitive awareness allowed them to break free from rigid patterns and explore flexibility in applying various modes of thought." One student noted that combining visual, causal, critical, analytical, and verbal thinking led to better results in the exercise.

The course also encouraged students to explore flexibility in using various modes of thinking, highlighting their complementary roles in problem-solving. In a class exercise, students were asked to visualize a single object that could pass through three differently shaped holes in a piece of wood. One student recalled using a memory of a toy as a reference, visualizing an equilateral triangle and square fitting together but struggling to imagine the bottom face fitting the circular hole. Another student, recalling putting shapes through holes as a child, remarked, "Remembering this helped me find a solution more quickly because I could easily visualize the separate shapes as I tried to combine them." This connection to prior knowledge and its application to new problems illustrated how visual thinking can evolve and integrate with memory and other learned skills. Students reported that "the course helped them refine their visual thinking, with assignments that challenged them to exercise the three visual elements—seeing, imagining, and drawing." Engaging with materials such as sketching and molding clay further enhanced their understanding. As many students remarked, the activity was "extremely engaging," demonstrating how visual thinking evolves through adaptation and hands-on experience. Reflecting on the experience, one student said, "I can identify how prior experiences become a frame of reference when developing solutions to problems, which allows me to conceptualize the idea of visual thinking and understand ways to apply it in my life." Another student reflected on the exercise's impact: "The shape exercise allowed me to conceptualize how visual thinking worked in my mind and how integral it was to finding a solution." One student shared how their "polysensory ability" helped bring the shape into focus through bodily thinking as they alternately pushed the clay through the holes.

In a student homework memory exercise based on an earlier life experience in designing and building a project, students were asked to foster visual thinking, engage the mind's eye, and strengthen connections to episodic memory. They began by reading a narrative titled Biplane Visualization. Students reported connecting with the "detailed process of visualizing information by sketching iterations," highlighting the concept of "thinking drawing" from the memoir. They recognized it as essential for engineers to refine ideas by translating mental images onto paper: "Thinking drawings take that vision and put it on paper... it helps engineers refine ideas with fewer iterations." One student recalled a high school AP physics project that sparked their creativity: "I remember feeling the neutrons in my brain awaken..." The project, which involved building a structure with a spinning motor and three circuits, ignited their interest in architecture and creative problem-solving. Another student, raised in a creative household, emphasized the importance of visual thinking but observed its absence in public education. Reflecting on their experiences, they noted, "Most of the concepts that have stuck with me were the ones analyzed through visual thinking methods." Similarly, another student described building a cardboard castle, drawing on their understanding of structural integrity, and realizing the power of visual thinking in connecting abstract ideas to real-world solutions. One student shared their reflection on how visual thinking shapes learning: “My favorite was the memory exercise... It allowed me to reflect on different projects I completed and sketch one from memory,” underscoring how visual thinking intersects with ideation, design, and problem-solving. Another reflected, “Thinking drawings take mental images and put them on paper, helping refine ideas.” Yet another recounted a past project that sparked their interest in problem-solving, saying, “This exercise reminded me of a physics project that awakened my creativity.”

In a class exercise involving Galileo’s observations and writings on the moons of Jupiter, students reflected on how visual and scientific thinking together enhanced their understanding of the world and their academic work. They drew connections to Galileo’s methods of visual observation, hypothesis testing, and scientific documentation. Galileo's innovative use of drawings and observational data to validate scientific hypotheses was seen as a foundational example. As one student noted, "Galileo revolutionized science by using visual observation to prove astronomical theories, making images a powerful tool for communication." Several students highlighted how his combination of sketches and written analysis advanced scientific inquiry, allowing complex data to be better understood. This integrated approach resonated with students, who saw parallels in modern science and technology, as well as in everyday life. One student observed, "Galileo's use of visual thinking, combined with testing and recording results, is interesting to reflect on given today's digital technology."

Through dialogues, students recognized the value of visual thinking not only in the scientific method but also in everyday life, viewing it as an essential tool for exploring problems. One student reflected, “Galileo used the scientific method and observational data, and we still apply similar techniques like pattern recognition in our daily lives to test ideas.” This connection between visual methods and scientific reasoning encouraged students to apply structured thinking to challenges in both academic and real-world contexts. Students also noted the broader impact of visual thinking beyond academia, with one student highlighting how “Galileo’s observations of Jupiter challenged preconceived ideas,” and how “this principle can be applied to everyday problem-solving.”

Conclusions

The findings presented in this study underscore the transformative potential of explicitly teaching and practicing visual thinking. Students consistently highlighted its practical applications, valuing visual thinking for its capacity to enhance creativity, problem-solving, and communication. By exploring both the neurological foundations of visual perception and analog practices like sketching and marginalia, students developed a holistic awareness of how visual thinking shapes learning and design. Exercises such as the ‘pierced holes’ activity and reflections on reasoning by figures like Galileo further illustrated the integrative nature of visual thinking, connecting scientific inquiry with creative exploration. These experiences reinforced the importance of cultivating visual thinking through curricula that prioritize both abstract and applied methods.

Analog practices—especially the use of blank-page notebooks—played a significant role in shaping students’ visual thinking and providing artifacts of their experimentation. Activities like sketching and "thinking on paper" (a term students used to describe externalizing thought through drawing and annotation) fostered nonlinear thinking, creativity, and iterative exploration, while supporting the systematic refinement of ideas. Incorporating personal experiences into the notebook process also broadened students' reflective thinking, ideation, and design cognition. These practices provided a tangible link between thought and expression, deepening students' connection to their work and enhancing their ability to integrate visual and verbal elements effectively.

Building on these analog methods, other key practices—such as hands-on observation and drawing—further supported students' ability to visualize and solve problems creatively. Emphasizing relaxed attention and interdisciplinary collaboration also enhanced critical and creative engagement, fostering a mindset conducive to innovation. Exposure to diverse practices across disciplines was similarly impactful, as students valued the varied perspectives and collaborative learning experiences their peers brought to the classroom. These transdisciplinary interactions encouraged students to view visual thinking as a flexible, widely applicable skill across fields, including the humanities, sciences, architecture, and engineering.

In engineering design, visual thinking emerged as a critical tool, enabling students to translate abstract ideas into visualizations, refine designs, solve problems, and communicate effectively. Students reported that sketching and visualizing early in the design process enhanced creativity, empathy, and the generation of impactful ideas. Similarly, the use of visual annotation and marginalia supported writing by deepening comprehension, encouraging critical engagement, and aiding iterative refinement. This practice helped students connect reading and writing as integrated components of learning.

Visual thinking also proved vital for communication. Through readings, student-led seminars, and collaborative activities, students developed critical, visual, statistical, causal, and scientific reasoning skills while gaining confidence in both graphical and verbal expression. These experiences demonstrated how visual thinking supports individual insight as well as collaborative learning, reinforcing its role as an essential component of a well-rounded education.

This study raises several questions for further exploration: How can visual thinking be more explicitly and systematically integrated into curricula across disciplines such as the humanities, sciences, social sciences, engineering, and architecture? What role might neuroscience play in informing pedagogical approaches to support visual cognition and perception? How might a deeper understanding of the visual system, when combined with visual thinking techniques, equip engineering students to engage more critically with ethical dilemmas—particularly those involving technologies that rely on visual data and may contribute to addictive visual stimulation, surveillance, or other harmful practices? The interplay between analog and digital approaches also warrants further attention: How might hybrid practices optimize creativity and iterative thinking? Practical challenges—such as limited class sizes and the need for inclusive strategies that support diverse learning styles—must be addressed to ensure equitable implementation. Long-term impacts on innovation, professional development, and metacognitive growth also merit sustained research.

Overall, the findings suggest that visual thinking is a vital and transferable skill that transcends disciplinary boundaries. It equips students not only to solve complex problems, but also to communicate more effectively, reflect more deeply, and engage more ethically with the world. Student responses across both secondary and postsecondary levels highlight a clear desire for more explicit instruction in visual thinking, underscoring the value they place not only on content knowledge, but also on how they learn to think, visualize, and create. These findings support the broader integration of visual thinking into educational curricula and emphasize its potential to transform not just how students learn, but how they perceive and act in the world.

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