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Undergraduate Research Experience Uses Drawing and Art to Bolster Understanding, Communication, and Innovation in Engineering

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Abstract

This paper highlights the impact that making art had on five cohorts of engineering students participating in a U.S. National Science Foundation funded Research Experience for Undergraduates program during the summers of 2019 to 2024 at the University of Kansas. Using a weekly incubator format, students were challenged to practice drawing exercises and graphic design principles and then apply these lessons in the context of their individual research project and laboratory environment. Evaluation of these experiences showed that the arts-based approach led many students to assimilate drawing as an observation and learning tool. Over 70% of the students reported they would continue drawing to interpret and present concepts with visual representation. These activities also enhanced the students' communication skills and led to more effective public speaking. The outcomes reinforce the established value of arts-based learning at promoting a host of skills, including innovation, observation, and communication.

Introduction and Motivation

We had three main learning goals in mind when we set out to craft a summer research experience for undergraduates (REU) site with funding from the U.S. National Science Foundation (NSF). These goals are to (i) nurture a sense of scale, (ii) foster an innovative mindset, and (iii) bolster communication skills.

Several pieces of evidence support these three goals. For example, research shows that students of all ages struggle to grasp differences in scale, especially at the size extremes where matter is miniscule or massive [1-7]. While not a new theme in science instruction, it is vital for students to understand absolute and relative scales, both for scientific literacy and to become effective science communicators. In addition, having a sense of scale also helps drive innovation [8-10], which is critical for the future competitiveness of the U.S. in the global economy.

Our strategy to achieve these goals involved enhancing conventional chemical engineering research experiences with arts-based learning. Inspired by how companies and universities use incubators [11-13] to promote novel thinking, we developed a framework known as IDEA Incubators, with IDEA standing for <u>i</u>ntegrating <u>d</u>iscovery, <u>e</u>ngineering, and <u>a</u>rt. A total of eighty students from five cohorts have participated in these incubators to date.

The reason for using arts-based learning in our incubators stems from the substantial body of research and practice showing its many benefits. For example, it promotes innovation [14-17], develops leadership [18], enhances teamwork and intercultural communication [19,20], fosters creativity [21], improves observational abilities [22], and strengthens communication [23], all essential skills for workforce development [24].

The National Academies of Engineering "Educate to Innovate" report [25] also informed our use of incubators as a learning strategy. This report identifies critical skills, experiences, and best practices for nurturing innovative capacity. Of the six environmental factors mentioned in the report as having a key role in innovation, our incubators supported three factors, including explicitly encouraging innovation, having physical spaces for free/informal discussions, and providing the freedom to tinker.

Several other activities besides the incubators expanded the breadth of learning during our REU program. For example, students toured an on-campus art museum and a commercial manufacturing facility. They also learned about the scale of the chemicals industry with interactive prompts. While these activities were key components of the program, they are not the focus of this paper. Instead, this paper focuses on how we integrated art and engineering in the incubators. We highlight the impacts, lessons learned, and several benefits of this training method, including how it helps undergraduate students learn how to observe, brainstorm, and communicate more effectively.

Methodology

The REU IDEA Incubator summer program was offered five times from 2019 to 2024, every year except for 2020 during the COVID-19 pandemic. A total of eighty students, averaging sixteen per year, participated in five two-hour incubator sessions, offered over a period of four weeks, from May to June. The lessons were designed to build skills sequentially, with each new incubator applying the concepts of the previous week and gradually progressing to build up a framework for visual communication and storytelling.

The progression of incubator topics is shown in Figure 1. Week one began with a basic overview of drawing and sketching. Students learned to apply fundamental drawing skills to describe concepts and data. The next week's lesson transitioned from individual drawings or images to combining images into a composition. For example, students learned how shapes, color, layout, and other aspects of a composition work together to send a message. They also analyzed visual abstracts, and journal covers to see how these concepts are applied in scientific communication. The third week focused on bringing multiple compositions together to present a storyline. Students learned about the basics of creating a narrative and the concepts of sequence and process. In week four, the concepts learned from the previous weeks come to fruition in designing a research presentation. Students learn that each visual image on a slide communicates something. Similarly, the layout and composition of a group of images also communicate a message. Thus, every aspect of a given slide should be intentionally and thoughtfully crafted. Finally, a sequence of slides (or compositions) come together to present a story or an overall message. In this case, the students applied these skills to communicate the relevance and main findings of their research projects.

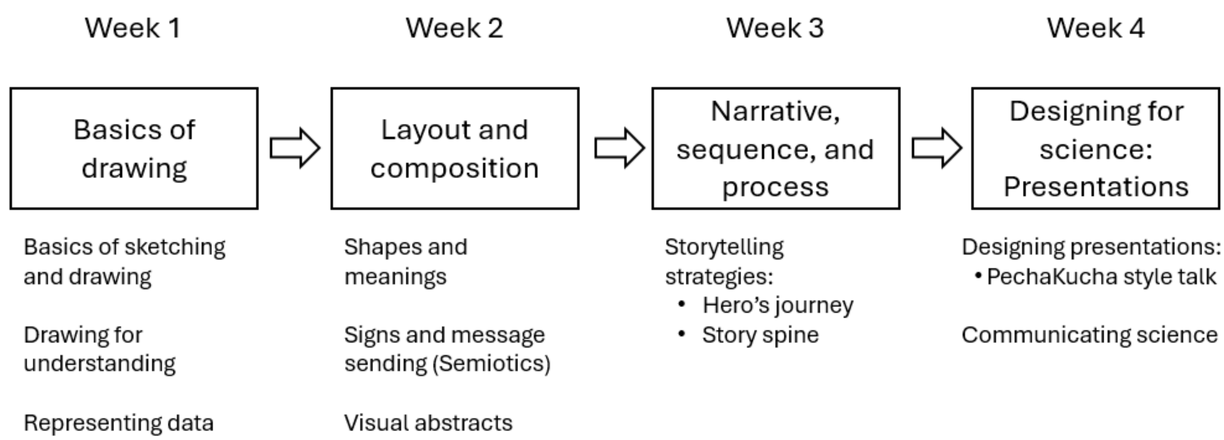


Figure 1: Incubator sequence design and content.

During the fourth week, students participated in two incubators: one focused on designing presentations and another focused on tools for communicating science effectively. They learned to adapt content based on the audience and goal of the presentation. They also learned that every word and inflection in the voice communicates something just like every line and every accent of the ink tells something in an image. Similarly, the combination of examples, analogies, and context sends a message to the audience just as a combination of images, shapes and colors form a composition. Finally, the choice of the sequence and order of the content can potentially make a presentation engaging (or not) by following storytelling principles.

A central exercise across all incubators was to practice journaling. Each student received a journal at the start of the summer, which was used to collect observations, questions, reflections, and sketches of their summer research experience. Many of the challenges and exercises given to the students required observing, recording, and tracking data. Participants had the opportunity to practice collecting information throughout the day and not only during the incubator sessions. For example, students practiced the 7-minute diary exercise by Lynda Barry [26]. Use of the journal was demonstrated and practiced at the incubators with a variety of exercises, including drawing warmups, visual analogies, visual representations of data, visual abstracts, among others.

After each incubator, students were challenged to apply the prompts, exercises, and design principles in the context of their individual research project and laboratory environment. The results were recorded in their journals, with several examples shown on the following pages. Lessons learned from the incubators also informed outcomes for the REU site, including a PechaKucha-style talk (modified to a slide show of ten images, each auto-advancing after 20 seconds [27]), a 15-minute research talk, and a scientific poster.

The REU activities were evaluated in several ways. Pre- and post-surveys were administered to assess perceptions, attitudes, and skills acquired from the program. An evaluator also led small group exit interviews with the students, gaining important insights about the program's impacts.

Incubator Outcomes

1. Outcomes of Week 1 Incubator: Basics of Drawing

The first week's incubator focused on the fundamentals of sketching and drawing, emphasizing how to use these skills to represent concepts and data. A summary of activities is provided in Table 1. The shared objective of these activities was to explore how the elements of a drawing convey a message. This approach helped students develop their observation skills and translate their observations into visual representations.

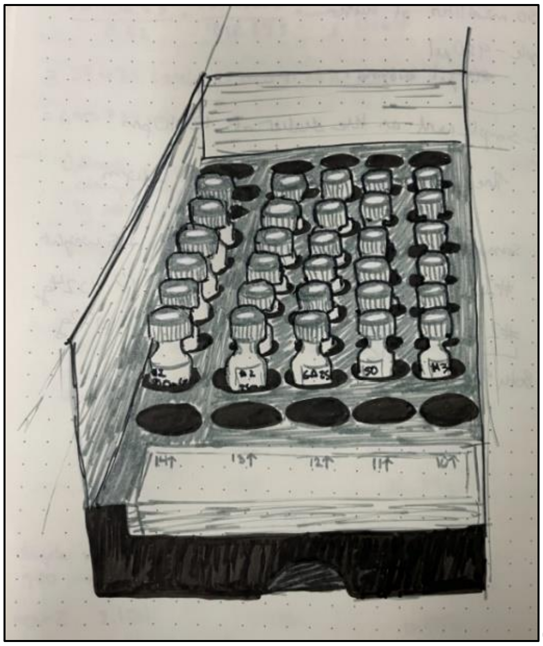
Table 1. Week 1 incubator activities emphasized the basics of drawing.

Activity	Summary of Activities for Week 1
Drawing for understanding	Using drawing as a tool to sharpen observation skills and pay attention to details; **Challenge 1:** Draw things from the lab daily for a week.
Representing size and scale	Using visual representation to make meaning of large or small numbers that are difficult to fathom without context or reference to other magnitudes; **Challenge 2:** Pick a number concept related to research/lab, and make a size/scale comparison to a few things to help build landmark understanding of the concept
Representing data visually	Represent data with non-traditional charts or plots that also communicate visually what the data represents; **Challenge 3:** Record data about yourself, then graph results visually.

1.1 Drawing for Understanding

Students first learned about how marks have meaning. For example, they learned that a single pen could make different meanings by drawing bumpy, smooth, sharp, soft, thin, heavy, or strong lines. Students then practiced what a mark means by drawing an object, such as pliers, with line hierarchy, details, and in business card size. Various examples of sketch artists were discussed, including Kate Bingaman, Julia Rothman, and Ivan Brunetti. Then, students drew themselves with a Brunetti style doing something in the lab, something fun, or something they love. These quick sketch-style drawings by professional artists illustrate to the students that an image does not need to be “perfect” or highly realistic to effectively convey a message. With practice, anyone can create drawings or images that communicate ideas clearly. In fact, these sketchy-style drawings are often an excellent and appropriate choice for delivering a message. Students also learned that it is not necessary to master the skill of drawing a perfect picture. By understanding the principles of drawing, they can select suitable images from search engines or AI image generators. Additionally, engineers frequently collaborate with professional illustrators to bring their visions to life.

Students were challenged to apply what they learned in this incubator by creating sketches of objects in their research laboratory. Examples of student drawings are shown in Figure 2. What stands out about these drawings is their detail. This exercise encouraged students to closely examine the objects, noticing features that might otherwise be overlooked. For scientists, strong observational skills are essential for identifying subtle differences. This type of drawing practice is common among ecologists sketching nature, it is less typical for chemical engineers but no less valuable. Not all student drawings achieved this level of detail, but nonetheless, every student that participated in the exercise had a valuable opportunity to improve both their observation and drawing skills.

(a) 

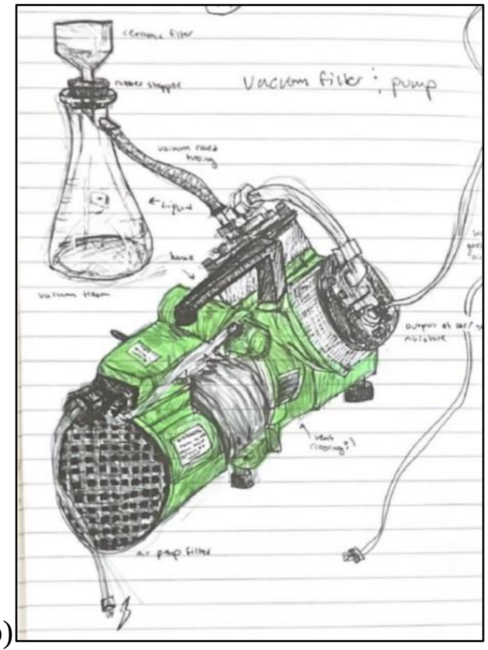
(b) 

Figure 2. Two examples of student laboratory drawings: (a) gas chromatography vials and (b) a vacuum pump connected to vacuum filtration system.

1.2 Representing Size and Scale

Drawing and sketching can be applied to create visual representations of concepts. In this exercise students were challenged to use drawings to explain a numerical concept related to their research. The goal was to make a size and scale comparison to something tangible, helping to build anchor points, or “size landmarks” [19, 21], that would aid in both understanding the concept and communicating it to others. Two typical examples of student work are shown in Figure 3. While students began to develop a sense of size and scale, the main takeaway was that visual representations serve not only as tools for learning but also as effective means of communicating new concepts. Many students applied this practice by creating their own sketches to better grasp concepts in their respective research projects. When preparing their final presentations and posters, many students incorporated these sketches into their slides and posters, as seen in Figure 4. Anecdotally, these students had not initially planned to include the sketches but did so after realizing how effectively the images conveyed the research concepts.

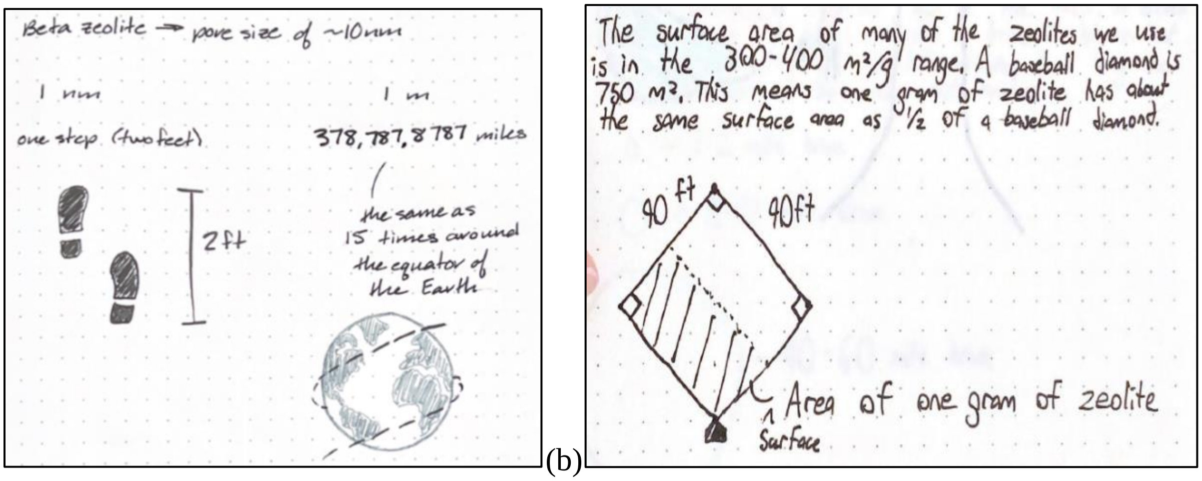


Figure 3. Two student examples of size and scale comparisons for zeolites, showing (a) pore size compared to a footstep and (b) surface area compared to a baseball diamond.

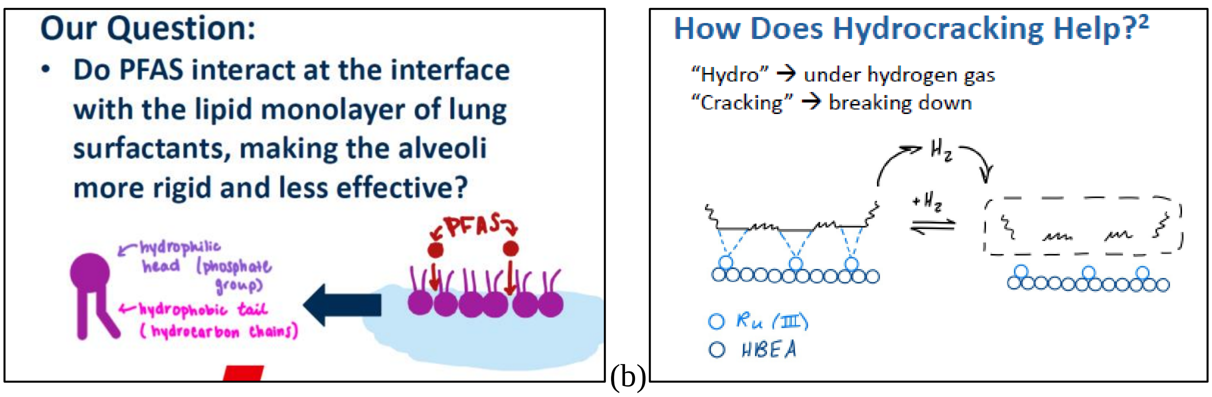
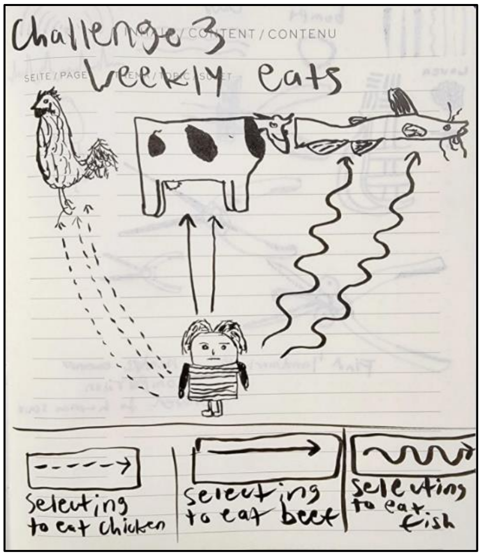


Figure 4. Selected sections of student research posters, showing examples of how they used their own sketches to explain (a) per- and poly-fluoroalkysubstance (PFAS) sorption on lipid monolayer in lung and (b) hydrogen transfer on catalyst surfaces during hydrocracking reaction.

1.3 Representing Data Visually

The exercise in this section followed the examples set in in the book "Dear Data" by Giorgia Lupi and Stefany Posavec [28]. For a week, students tracked some type of information from their daily lives and recorded it on their journals. At the end of the week, they created a non-traditional chart to summarize the data and shared it with the rest of the group. For example, one student decided to track their choice of protein at lunch (Figure 5a) while another student tracked time spent practicing the violin (Figure 5b). Other examples (charts not shown) included keeping track of records listened to, amount of sleep per day, miles run or walked, tv-show episodes watched, distance driven, and many more. All students, without exception, produced creative chart designs to represent the data recorded.

(a) 

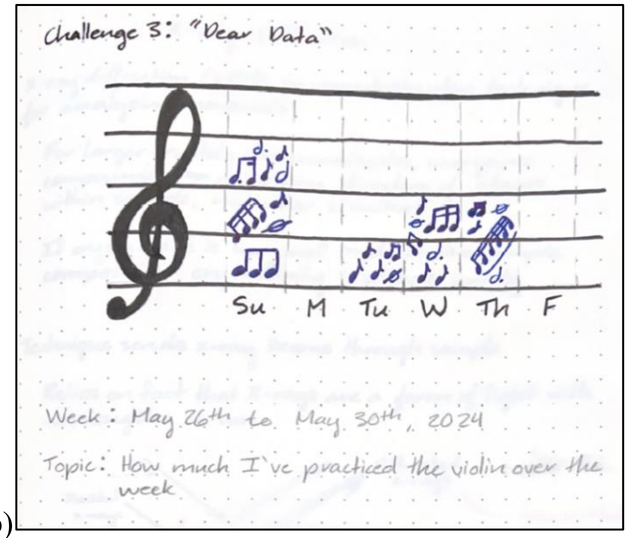
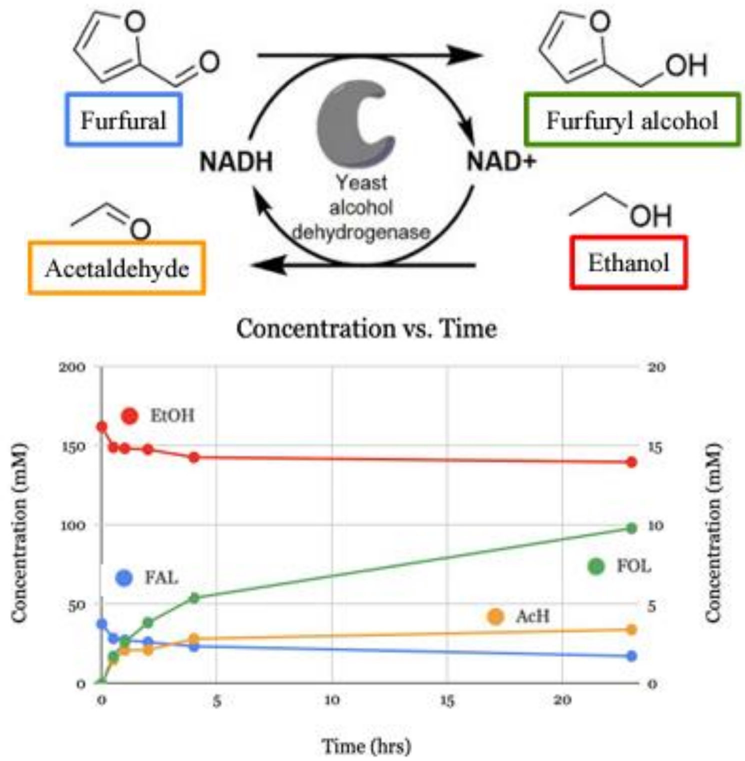
(b) 

Figure 5. Examples of students visualizing data collected from their own lives. (a) Student represented their choice of protein at lunch with different styles of lines. (b) Student tracked violin practice with each space on the music staff representing 1 hour of practice.

These non-traditional charts allowed the students to practice the creative organization of parts, learning new ways to communicate quantitative data with images and drawings. Moreover, this exercise had several elements applicable to effective science communication. It helped students think about more effective ways to visualize quantitative data in a graph to make it easier for the audience to understand. For example, one student used color coding on different parts of the research poster to refer to molecules in a chemical reaction, as shown in Figure 6a. This visual aid made it easier for the audience to interpret several charts showing concentration as a function of time (Figure 6b). This activity had other benefits for the students as well. They had to be more mindful of aspects of their daily routines. Also, they had to practice their observation skills, paying close attention to track the datapoints. As a result of this, some students commented that they learned something about themselves that they had not realized before.



(a)

(b)

Figure 6. A student used color coding in multiple images/charts on a poster presentation to make it easier for the audience to understand, as shown by (a) color-coded molecules and (b) how the concentration of those molecules changed over time in the chemical reaction.

2. Outcomes of Week 2 Incubator: Layout and Composition

The second incubator focused on bringing together multiple images to communicate a central message, as summarized in Table 2. With an overview of principles of design and composition, students learned how different elements come together to present a visual message, including contrast, proportion, repetition, alignment, proximity, and others. Students also studied concepts of signs and message sending (semiotics) and learned the meaning of a symbol, icon, and index. In addtion, students analyzed and interpreted, as a group, the meaning of various visual abstracts and journal covers; studying the principles and design elements that produced the desired message.

Table 2. Week 2 incubator activities emphasized layout and composition.

Activity	Summary of Activities
Mood board	Study elements of composition in example mood boards.; **Challenge 1:** Create a mood board that evokes the feeling, mood, and/or topic of your laboratory or research project experience
Generating ideas	Stream of consciousness thinking; mind maps; **Challenge 2:** Generate a word list and a mind map with ideas related to their research project.
Thumbnail sketching	10 ideas in 10 minutes with thumbnail drawings; using thumbnail sketching to brainstorm ideas to communicate a message graphically; **Challenge 3:** Set a 10-minute timer and generate 10 thumbnail ideas for a visual abstract for their research project.

2.1 Mood Boards

To practice the principles of design and composition, students were challenged to create a mood board about their research experience in the laboratory. A mood board is a collage or arrangement of images, materials and small portions of text that evoke or represent an idea, a mood, or a style. Students were tasked with creating a mood board that represented their experience in the laboratory by combining an array of images and considering basic principles of composition. A sample of the students' work is shown in Figure 7.

(a) (b)

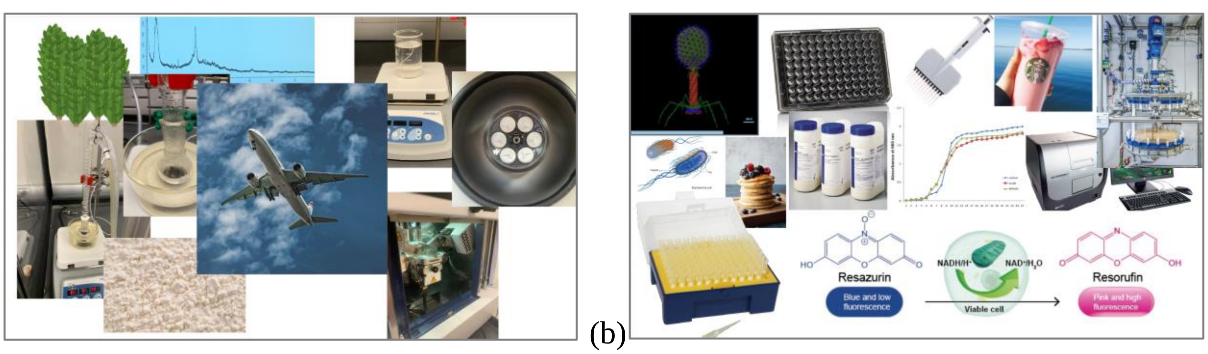
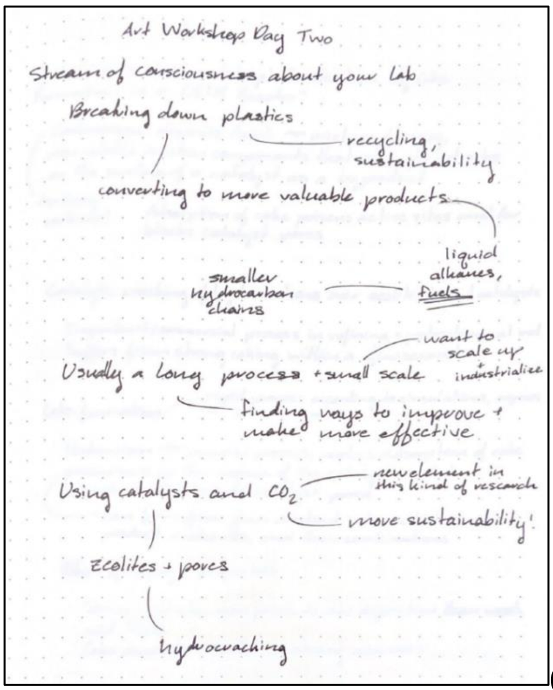


Figure 7. Sample mood boards created by students about their laboratory research projects related to (a) production of jet fuel from biomass-derived lignin and (b) making dental fillings with enhanced anti-microbial properties.

2.2 Generating Ideas

Next the students were challenged to generate ideas for a visual abstract for their research project. As part of the creative process, they began by generating a list of words related to their research, jotting down every word they could think of as a "stream of consciousness." Then, they made a mind map for all the words linked to a key research concept, beginning with a key word and then adding various branches of related terms out from each word added. Examples of these exercises are shown in Figure 8.

(a)



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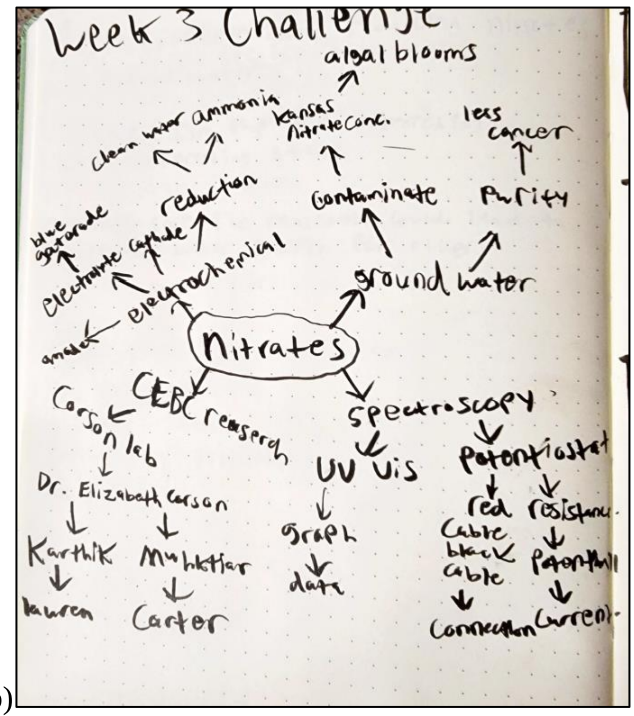


Figure 8. Samples of students' creative process to generate words and concepts related to their research. Stream of consciousness (a) thinking and mind maps (b) provide ideas that will later inspire the creation of a visual abstract for the students' research projects.

2.3 Thumbnail Sketching

Out of the inventory of words and ideas generated in the exercise above (2.2), students were challenged to create 10 thumbnail sketches of potential compositions that could turn into the visual abstract of their projects. The goal was to brainstorm visual compositions that describe the scope and key ideas of the research and use a style fitting for a journal cover. Prior to this, students analyzed various real examples of journal covers and interacted with the researchers and graphic designers that created the covers.

The thumbnail sketching challenge combined the concepts learned in the incubators in weeks one and two with the topic of their respective research. Now that students have practiced the basics of drawing (week 1) and the fundamentals of design composition (week 2), they could create a composition that communicates a central message about their research. Students were prompted to set a 10-minute timer to create 10 thumbnail sketches for visual abstracts. As shown in Figure 9, this activity gave students a chance to practice layout, message-sending, hierarchy and storytelling in a series of quick sketches.

Most thumbnail sketches created by a single student evoked something about the central idea of the research. Also, each thumbnail highlighted a slightly different aspect of the research. In a sense, the entire set of thumbnails communicated a more complete story than each individual one. Therefore, a new version of the visual abstract would likely include a combination of elements of the various thumbnails. This was the case for a student that took the next step and created a full design of a journal cover as seen in Figure 10. This design corresponds to the sketches in Figure 9b, and it is apparent that many elements, patterns, and colors of the full version evolved from the sketches.

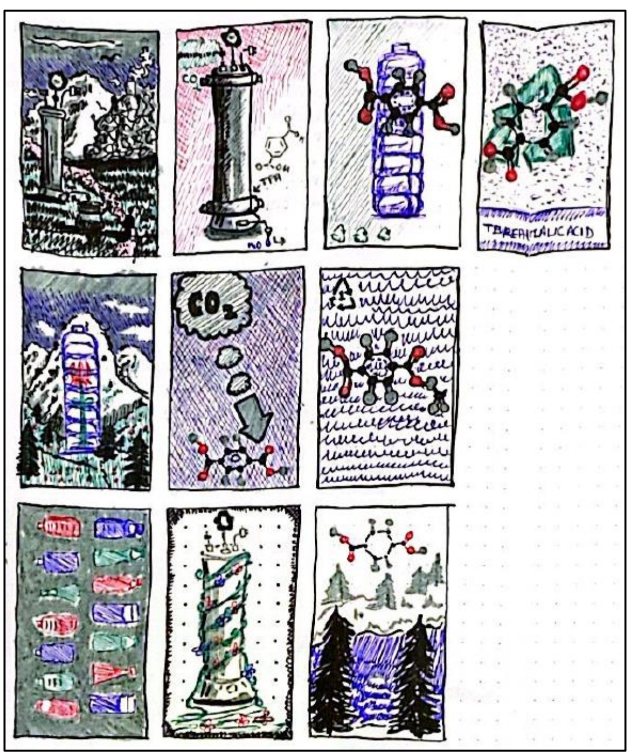
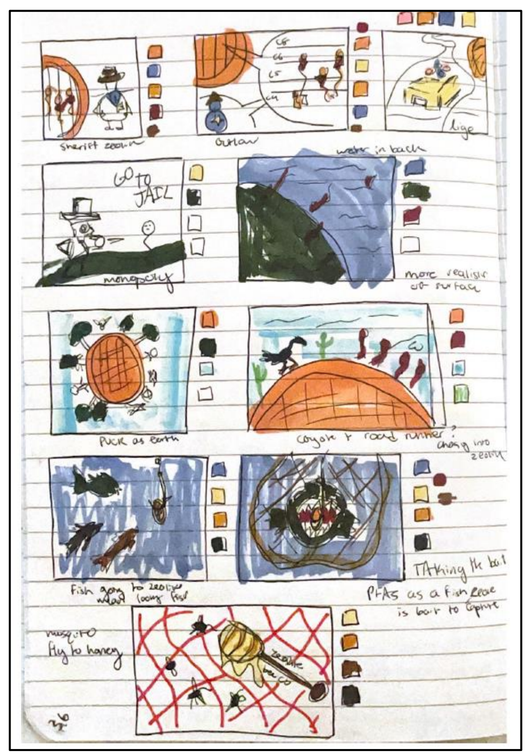
(a) 
(b) 

Figure 9. Samples of students' thumbnail sketches of potential visual abstracts for their research, showing (a) depolimerization and separation of monomers of a plastic polymer, and (b) removal of per- and poly-fluoroalkysubstance (PFAS) from water.

Figure 10. A student created a visual abstract for their research project related to the removal of per- and poly-fluoroalkysubstance (PFAS) from water using zeolites. This visual abstract evolved from a set of thumbnail sketches shown in Figure 9b.

3. Outcomes of Week 3 Incubator: Narrative, Sequence, and Process

In this session students learned different storytelling strategies and practiced creating visual narratives. In the previous incubator, compositions were created from an arrangement of multiple images or drawings. Now, compositions are organized in sequence to create a story or a process. Each composition has its own central message and a purpose as part of the whole; and students practiced how to structure the sequence to share a message effectively.

Table 3. Week 3 incubator activities emphasized narrative, sequence, and process.

Activity	Summary of Activities
Storytelling strategies	Reviewed "the hero's journey" framework, story spine, and other strategies for storytelling; **Challenge 1:** Create a story spine related to their lab, their field of study or how they came to be part of this summer experience.
Memory map	Practiced visual storytelling by creating a personal story with a memory map; **Challenge 2:** Draw a line with 6 beads with a frame next to each bead. Then tell a story by drawing images in each frame

3.1 Story Spine

Students were prompted to develop the key points of a personal narrative following a simple structure or "story spine." Then they presented it as a visual story in a subsequent exercise. The prompt included four parts: (1) Introduction, (2) Status Quo, (3) Inciting incident or catalyst, and

(4) Resolution. Some options for the topic of the story included their research experience, field of study, or the life events that led them to this program. Student choices of topic were diverse, and some created multiple story spines. Most students wrote about the life events that led them to this program, with many others writing additional story lines about their love of science, the summer research experience, or aspects of their research project.

The incubators were intended to foster a low-stake space for experimenting and practicing. Students had fun creating narratives about familiar topics, while also practicing and developing skills for effective communication. Additionally, students shared their work with each other during the incubator sessions helping them to learn from everyone's experiences. Parallel to these exercises, they also conducted research in their laboratories, making it possible to practice connecting art skills with research for poster and oral presentations.

3.2 Memory map

Students took the story spines created in the previous exercise and re-told them visually in a "memory map," which is a hand drawn, curved line with six beads. Connected to each bead was a visual composition that represented a key moment in the story. Figure 11 shows an example of a memory map of a student's life events that led them to this program. The short text captions help interpret each frame, but the drawings communicate more about the story. These particular six events are likely hinging moments in the path to where they are today, which draws attention and interest from the audience. In a sense, this visual depiction is an outline of the story, a graphic representation of the story spine. Students learned that they could adapt this story for any format and presentation length. With more time or more "beads," one could simply expand on each of the frames, keeping in mind that the central message still depends on the key events of the story. This holds true for a research talk or poster. The key points of the research project could be listed and explained succinctly for a 5-minute presentation. For a 30 or 60-minute presentation, the same key points could be expanded and more details added, but without losing the essence of the story.

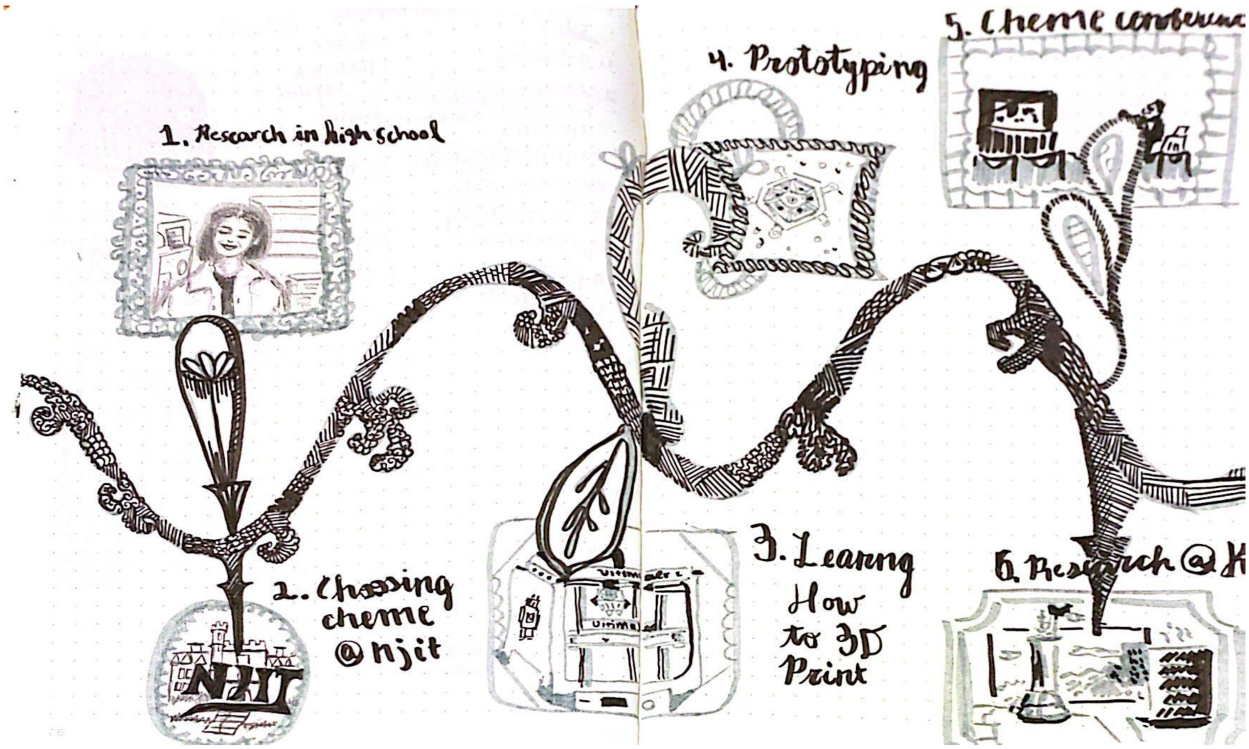


Figure 11. Sample student "memory map" based on the life events that led them to join this summer research experience.

Students also created visual descriptions of processes or sequences. For example, a student described "the process" to make friends with their peers in Figure 12a. The same student applied the same exercise to create a "memory map" depicting a methodology in the laboratory (Figure 12b). Interestingly, in the final research poster, the student presented the project methodology with a sequence that resembles their submission for the incubator exercise (Figure 13).

(a)

(b)

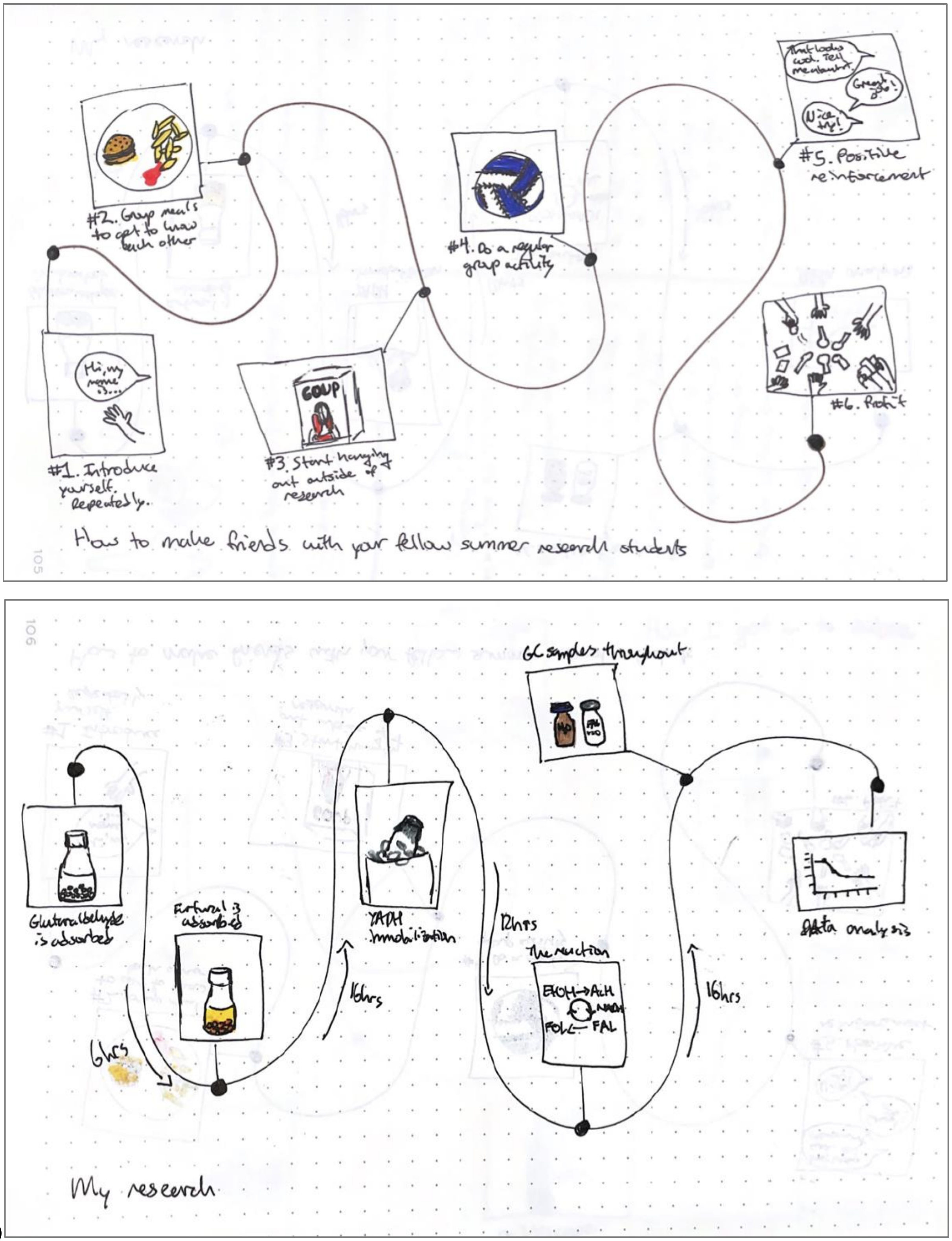


Figure 12. Sample "memory maps" created by a student for (a) how to make friends with their peer undergraduate researchers and (b) a process or methodology of their research project.

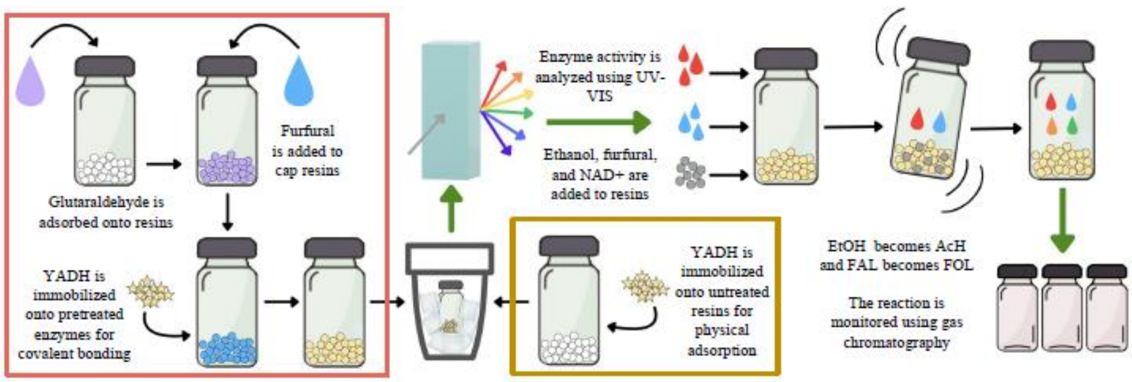


Figure 13. Methods description in student's final research poster. The sequence presented resembles the submission for an incubator exercise shown in Figure 12b and the color-coding in Figure 6.

4. Outcomes of Week 4 Incubators: Science Presentations and Science Communication

In week four, students participated in two complementary incubator sessions on (i) visual design of science presentations and (ii) communicating science effectively. Both sessions leaned on the concepts studied the previous three weeks of incubators, which are transferable to making a research poster or oral presentation. Everything put on the page or slide communicates something. Not only the text but the color, the font, the size, the place. Thin or thick; it is communicating something. Students learned these lessons from the theory of drawing and communicating information through images and applied it back to communicating science. Even the inflection in the voice can be a strong stroke or a thin stroke. The presenter's excitement, eye contact, and gestures all communicate information to the audience. Just as extra lines in an image can distort or blur the picture, words, or gestures out of place can blur or distract the audience from the central message.

Table 4. Week 4 incubator activities emphasized communicating and presenting science.

Activity	Summary of Activities
Incubator 1: Communicating science	How to explain clearly why a topic matters, how to make a message memorable, how to recognize and apply communication for different audiences
Incubator 2: Design of science presentations	Reviewed all the concepts from the first 3 weeks of the incubators and learned about PechaKucha presentations with multiple examples; **Challenge 1:** Prepare and deliver a PechaKucha style presentation with 10 slides and 10 seconds per slide

4.1 Communicating science

The science communication incubator focused on practical strategies for explaining why a topic matters and how to make a message memorable. The content was designed to complement the other incubator elements, helping students understand and apply the various principles for more effective public speaking.

A mirroring activity was used as a warm-up, with participants standing and mimicking the leader's actions. The movements started chaotically and quickly, transitioning to simpler and slower movements. This exercise illustrated key public speaking techniques, including the importance of keeping a presentation simple, pacing appropriately, making eye contact, and observing the audience responses to foster connection.

The discussion emphasized the importance of giving the big picture context for a research project during a presentation. Participants practiced responding to the prompt: "My research is important because…" and then selected a target audience to consider how their research might impact that group. Understanding what matters to the audience is a critical first step in crafting a message that will engage them effectively [29].

To make messages memorable, or sticky [30], strategies such as storytelling and the 'and-but-therefore' framework [31] were introduced to engage the listener/reader. Vivid descriptions and vigorous verbs were discussed as tools for making abstract concepts more tangible. The importance of contextualizing numerical data and asking unexpected questions was emphasized. Students also practiced describing what it feels like for you, your family, or a community to experience the problem that your research is trying to solve. Moreover, they used other senses (sight, sound, smell, taste, touch) to describe their research, which gave rise to memorable examples such as, "*my research smells like a nail salon*," and "*I feel like a ghostbuster, carrying instruments on my back*."

We offered a similar communication training to students from other REUs and summer internships. Post surveys showed that most students rated the science communication training highly, saying they were likely to use the information they learned, as shown in Figure 14.

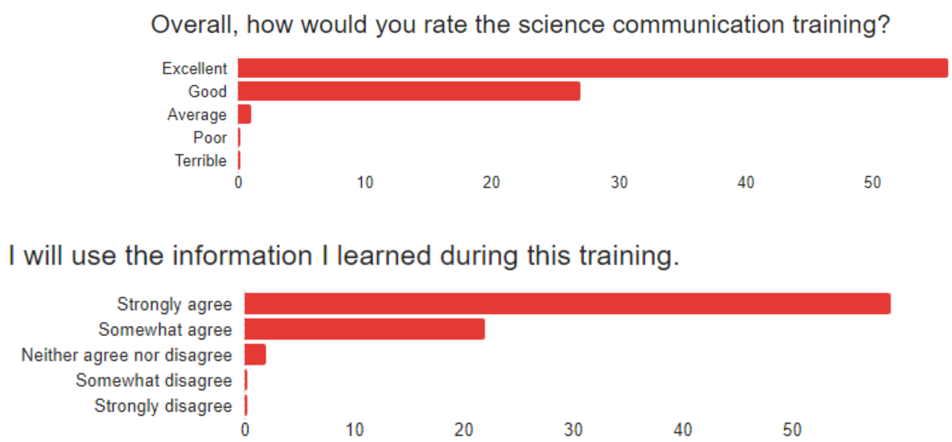


Figure 14. Survey results of students attending science communication training.

4.2 Design of science presentations

This session began with a review of the topics covered and practiced during the first three incubators, drawing connections and parallels to the process of creating a research presentation. To build on this skill, students were introduced to PechaKucha-style presentations and tasked with preparing a modified version based on their research or a personal story. Each presentation had to include 10 slides, with each slide displayed for 20 seconds before automatically transitioning to the next. The total presentation time was 3 minutes and 20 seconds. Given the brevity of this format, students must distill the key points of their message into a cohesive and compelling narrative. They were encouraged to incorporate their work from the incubator sessions, such as using the mood board as a visual aid for the opening slide or leveraging sequences from memory maps to explain their research or methodology. Personal stories may also be used to provide context for their research or to engage the audience's interest.

Every PechaKucha-style presentation created by the students demonstrated a clear connection to the preparatory work from the incubator sessions. Many students incorporated their own sketches, mood-board-inspired content, and visual sequences to explain processes and share personal experiences. Most students excelled in producing visually engaging materials to enhance their presentations and structured their narratives within a compelling problem-solution framework. Nevertheless, some students appeared tentative when talking about the technical content of the presentation, which is understandable given they have only been working on their projects for about five weeks. Many were nervous since this was their first experience presenting their research and attempting to craft a complete narrative about their work. The first three weeks of the incubators focused on creating and telling stories visually while week 4 incorporated public speaking. These presentations were the students' first practice at public speaking supported by effective visual aids, and they received valuable feedback to improve upon their visual aids and public speaking for their final presentation and final research poster.

Key Findings

Our summative evaluation of the REU program showed that the arts-based learning approach led many students to assimilate drawing as an observation and learning tool. Some students reported using sketches to brainstorm ideas for an experimental set up, or to troubleshoot an instrument that was not working properly during the program. Overall, they had very positive experiences.

For example, a student shared how they solved a problem in their experiment:

> *I find myself a lot more open to sketching… some of my experiments haven't been working, and it's taken so so so so so much brainstorming to figure out what even was remotely going on. It was a little bit exhausting, experiencing consistent failure after failure for almost a month…But today, we were able to finally make a major breakthrough, and it was largely due to a brainstorming session. Normally, I wouldn't be comfortable suggesting ideas that didn't guarantee a fix, but one of the many suggestions I had, actually worked! … But it took a lot of thinking, and it was a little outside of the box. I'd listed things out, kind of like word vomit, and highlighted all the things I thought might be relevant. I'm glad I did, so I really appreciate [the incubator] on that.*

Another student wrote,

> *I also really love the notebooks. The first thing I spent my first stipend on was another one. Additionally, I found myself kind of in a creative slump, coming into the summer, and this program has really helped me get back on my feet…I feel like I'm able to work through some of the less comfortable aspects of failure and get to the other side of a work in progress, more enlightened and satisfied with my work.*

Students generally thought the incubator activities were interesting, engaging, enriching, and helpful. Specifically, they mentioned the REU activities made them "*think more critically and be more adventurous with my experiments*", "*increase my creativity in explaining a concept indirectly, for example, when we had to present a timeline in six pictures*", "*practice how to turn words into a visual picture*". They also mentioned that the activities exposed them to "*a variety of research topics, which greatly enhances my creativity for coming up with research gaps*."

Storytelling activities seemed to be students' favorite part of the REU, with a lot of positive feedback. Many mentioned that they were struggling with telling their personal stories before participating in the REU; but from these activities, they learned to make their life experiences into a short and interesting story.

A few students mentioned that these activities also helped them have a better idea of their own identity and passion. It made them think more about what they are doing and why it matters. They said,

> *I liked learning about how to incorporate my personal story as a part of the REU program, but I feel that I personally had trouble trying to figure out how I would want to tell my story. I believe that for presenting biomedical/chemical engineering research, being able to tell my story and projecting my identity outward is important.*

> *I liked telling my personal story through the PechaKucha and tying that with how I got to this research experience. It helped me confirm why I am here and affirmed my passion for learning.*

> *Telling others about my personal story may give them an idea about who I am, what I'm doing, and why it matters.*

Students thought these activities were very helpful for their presentations at the end of the program. More importantly, they believed these activities would help them in their future research. They mentioned,

> *These activities definitely will help with the final presentation and the posters, as well as future public speaking events. As well as presenting, it also helps with listening and questioning skills.*

I really liked learning about storytelling from Kent and applying it to presentations. I think that it helped with my research in that it allowed me to create a presentation that did not feel like I was regurgitating information I learned-- it provided direction to a presentation.

I believe telling stories in drawings and pictures was a lot more fun than the original way. I can apply this method to my research when presenting to help the audience have a better illustration of what they are listening to.

Similarly, students enjoyed graphic design or art-related activities. They thought these activities helped them visualize and contextualize their research,

I liked the graphic part a lot. The sketching has helped a lot with visualizing what's happening and what devices I'm using in the lab. It provoked me to take more pictures and record more of what I am doing in the lab.

I liked these art-oriented activities. I think these activities helped me contextualize what presentations are like and helped me understand what I would need to do to present.

Kent did a great job making us understand the importance of various art forms in research. The activities gave us a few fundamental tools for our toolbox.

Students considered it a way to communicate with people outside their research field,

I really like Kent's contribution with the graphic design/symbols etc. I think it will help relay information to people in and outside my research and will be very helpful for creating posters that capture people's attention. I also think the sketching activities will help with creating schematics.

They also thought that these activities helped them become more creative, especially in their poster and research,

> *I feel the art activities helped me expand my creativity with respect to my research. I was able to draw some nice journal cover pages that helped me visualize my research and express it in a simple, graphic, way.*

> *The assignments such as thumbnails, mood board, and landmark numbers allowed us to think out of the box. I also really enjoyed the examples Kent gave of work he has done for journal covers.*

They mentioned a few specific activities that they enjoyed attending, such as mood board activity and mental maps,

> *I really liked the mood board activity we did at the beginning. I feel like it forced us to take the complicated ideas of our research and simplify it in a way that's visually pleasing i.e., attention grabbing which will be very useful for our posters/slideshow presentations.*

> *I really liked the mental maps and being able to write out my ideas in a stream-of-consciousness manner as I work through my ideas and figure out what I want to do with a presentation.*

One student mentioned that these activities also helped them discover their potential in art,

> *An interesting fact is that I didn't know I was quite capable of drawing things until I forced myself to come up with a drawing.*

Over 70% of the students reported they would continue drawing to interpret and present concepts and data with visual representation. Another notable outcome was the impact that the drawings had on the students' communication skills. Understanding the principles that make graphic messages effective led students to apply similar concepts to enrich their oral presentations.

Conclusion

This document highlights the power of integrating engineering and art as a vehicle to enhance science communication and innovation. The progression of art-based activities presents a methodology to help students understand concepts of size and scale in general and concepts specific to student research projects. Sketching and journaling were valuable in both troubleshooting ideas to solve research dilemmas and brainstorming ideas for research and communication efforts. Finally, the various techniques, combined with an understanding of graphic design principles, offer a valuable foundation to learn and improve public speaking.

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