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STEAM, Informal & Illustrated: Comics as a Supplemental Learning Tool

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Work In Progress: STEAM, Informal & Illustrated Comics as a Supplemental Learning Tool

Abstract

Traditional schooling fails to maintain STEM student interest for youth as young as 10 years old. Discouraged children self-eliminate from the pool of next generation scientists, emphasizing our need for engaging educational tools. Known to be a potential effective educational tool as early as the 1930s, comics combine imagery and written text to build a new type of educational reading. Visuals, dialogue, and diverse character sets can capture attention and diversify education. Our comics in collaboration with AIChE cover topics from chocolate to complex reactor design are developed to introduce chemical engineering concepts to K-12 audiences. Previous results from our group have indicated that integrating comics into educational settings increases student engagement and confidence, with additional potential to improve student understanding. With interest in expanding earlier studies to K-12 students, we developed an informal STEAM learning program designed to assess the impact of comics on participant learning carried out at Boys and Girls Clubs in the Greater Boston area (IRB # 24-06-32).

An interactive demo alongside simple surveys assesses student interest, engagement, understanding, and retention. Built to compare between a comic study group and a non-comic control group, we can consider participant learning preferences in combination with comic effectiveness. In this demo, participants learn the differences between chemists and chemical engineers, how to make paint from milk, the science behind it, and utilize the developed tools to communicate artistically. To support the learning from the demo, a six-page comic describing the steps of making milk-based paint was developed and printed, with half of the participants receiving the comic as a take-home learning tool. While student learning will always be unique per individual, our research shows comics offer a broad promise as a supplemental tool for STEM education. These studies have the potential to establish groundwork for comics to be used as supplemental learning tools in the K-12 space.

STEAM & Education in 2025

Research has shown STEM-based education as a powerful method for developing critical thinking skills [1]. However, incorporation of an intertwined curriculum remains challenging [2] impacting children as young as 10-years-old losing confidence in STEM [3]. Though beyond the scope of this paper, this STEM background is essential when considering the broader initiative, STEAM, including A for art [1]. STE(A)M realizes that mathematics and art are intrinsically connected, from fractals to digital design. Art naturally drives inspiration, and in STEAM, art provides the necessary flexibility for a new integrated, transdisciplinary approach. The motivation for art in STEAM further diversifies the population of those who can relate to STEAM and therefore make an impact in the field. Since the incorporation of art, humanity has become the focus in complex, real world, problem-solving and those practicing STEAM ideology become more well-rounded with new skills [1].

As with most changes in curriculum implementation, challenges remain. The most documented challenges highlight student understanding, lesson timeliness, and school district acceptance.

Other comments focus on challenges in STEAM assessment [2]. Despite STEAM education promoting creativity and self-efficacy [4], new tools need to be developed and designed for integration in order to serve a variety of learners and successfully communicate complex scientific ideas.

One of the most traditional scientific communication tools is the textbook, often text heavy with supporting visuals. Textbooks and other standard tools rely on active cognitive participation by the reader. Unfamiliarity or predisposed conflicting beliefs can easily sway readers away from engaging with such scientific learning tools. Introducing a narrative and increasing visuals are proven ways to re-engage or hook a reader onto a topic they might otherwise avoid. Comics, a visual narrative, can engage readers both cognitively and effectively through emotionally relatable characters. The cause-and-effect structure that comes from incorporating science into a narrative engages the brain in a different way, increasing retention beyond statements of arguments or facts. Previously overwhelming complex concepts now present themselves as more digestible. This intrinsic digestibility of comics can support readers who are unfamiliar with science concepts without the mental block from a wall of text. Comics have a unique ability to engage readers and offer a more accessible introduction to science concepts [5].

Science comics have been making their way into classrooms for decades to engage student interest and understanding [4, 6]. Over these years, research on how comics impact student learning is often roadblocked by rigid school structure or lack of support. Low curriculum flexibility in the K-12 space results in small sample sizes and presents limits in comic research. Despite these research limitations, studies have shown that students who find the comics interesting are more likely to remain engaged with the material and elect to read more science comics [6]. Art incorporated into STEM subjects shows increase in student motivation and active cognition in processing ideas [4]. Determining how these science comics motivate learners and what type of learners they motivate best will allow for a more targeted effort to expand educational tools and support students of any age.

Potential of Comics in Education

Comics gained popularity in the 1930s, re-emerging as an art to boost morale during the Great Depression [7]. Soon after, public support for comics dropped dramatically due to the censorship of the 1950s [8]. Comics began returning to mainstream around the 90s with a graphic novel winning a Pulitzer Prize Awards (the only to ever do so, Maus by Art Spiegelman) [9], increasing popularity for movies with comic origins, alongside the publication of Scott McCloud's, Understanding Comics. McCloud's meta-comic communicated how juxtaposed images with text build a world beyond words alone, effectively breaking down communication techniques and providing a how-to for effective comics with purpose [10].

The field of comics continues to investigate how readers engage with comics as visual mediums. Eye-tracking experiments have shown that readers interpret a visual language [11], without preferences of images over text or vice versa. Text and images can combine to create a "language" beyond the sum of its parts. Comics have served as instruction across many settings such as bathroom hand washing cards or COVID-19 test instructions, but they also function as narratives in superhero stories or retellings of history. In all cases, they have succeeded in the dissemination of information in a unique and powerful way. In determining what factors maintain engagement, comics can be evolved to better engage students and support their STEAM education (and possibly careers).

Recent work in the undergraduate space has shown those who had comics implemented in their classroom observed significant increases in their exam scores over the course of the semester [12, 13]. These comics focused on chemical engineering concepts including but not limited to, fugacity, uncertainty, and data analysis [12, 14, 15]. Comments from students support that comics were a less intimidating approach to learning and nearly all students discussed or recommended comics to their classmates as a learning tool. Since then, the chemical engineering comics for the undergraduate audience has been implemented at over 50 learning institutions and companies [12]. Determining what makes comic delivery successful in the classroom can empower others to incorporate comics in their own lessons.

Figure 1: Example science comic, "Hair Dye is Chemical Engineering"

Study Motivation & Design

Participants are handed paper surveys to gather information on their interests, preferences, motivation, and understanding of the material. To minimize survey stress, the questionnaires are split into a short preliminary survey and a longer exit survey. Most survey questions are borrowed from the MUSIC Model of Motivation [16] and Felder Solomon's Index of Learning Styles [17]. The remaining questions are specifically related to the chemical engineering content to quiz participants on scientific understanding. Finally, two questions are included to estimate participant interest in STEM and comics. Parental consent is obtained through the Boys and Girls Club previously established line of communication.

This study aims to report how comics support chemical engineering learning, specifically as a supplement to an interactive demonstration in an informal context. The comic, "Milk Paint is Chemical Engineering" [18] was written by our research team at Northeastern University in collaboration with professional artists, to supply the underlying concepts alongside each step of the demonstration. In two scheduled sessions at participating Boys and Girls Clubs in the Greater Boston area, surveys assess motivation, understanding, and learning preferences. Each group runs through the interactive demo with the same graduate student facilitator. The study group is supplemented with either an opportunity to read silently through the comic or a joint read through with the group, where the control group has no supplementation.

Using extracted questions from the Felder Solomon Index of Learning Styles [17], we can incorporate preferences of visual versus verbal learning in the final observations. As comics are a highly visual medium, including learning preferences in analysis can highlight that science comics benefit some but not all portions of the population. This information is helpful for the implementation of new educational tools. The remainder of the survey incorporates "questions" derived from the MUSIC model of Motivation [16]. Across nearly 20 statements, 5 key principles of perceived motivational strengths or weaknesses of instruction are measured via participant's ranked agreement or disagreement. Averages across 3-4 statements per principle, of these being, eMpowerment, Usefulness, Success, Interest, and Caring, support educators in understanding how the instruction engages each student individually [16].

These concepts were developed based on the understanding that student motivation is built upon this social-cognitive theoretical framework. In the satisfaction of student psychological needs, students become more engaged with learning, thereby increasing their likelihood of performing well academically [16]. Incorporating the MUSIC model with this study aims to determine how science comics might engage participants. Such findings could relay that though participants may not be interested in the learning material itself, the empowerment participants find in their connection to the characters could possibly outweigh the need to tailor comics to specific subject interests. When incorporating learning preferences, we might find differences in who and how participants best engage with the material. These combined surveys serve to quantitatively measure how comics support participant learning in supplement to an interactive demo.

The increase of participant exposure to chemical engineering concepts via comics is expecting to increase retention and understanding. To measure this, 3 questions are included to evaluate how much of the content the participants understand, following the same chemical engineering language used in the comic (separations, phases, methods). The calculated "quiz" score is combined in analysis with the participant data to determine science comic success as an educational tool in informal contexts. For example, it is further hypothesized that participants who prefer visual recall will have an easier time remembering the concepts disseminated in the comic, compared to participants who prefer verbal communication, or compared to participants who are in the control group. The assessment of comics effectiveness for participants with different learning preferences may support a more informed integration of comics in a classroom.

Upon survey collection, results are digitized, anonymized, and then evaluated as previously reported [16, 17]. The data are then uploaded into GraphPad Prism for assessment.

Comic Development & Conversation

"Making Milk Paint" is adapted for the K-12 space following a previously published ASEE K-12 demonstration [19]. The dialogue between student and teacher follows the underlying theory alongside the protocol's step-by-step process. Visual imagery is designed to support understanding of chemical engineering concepts. The chemical engineering concepts that are highlighted in this comic include chemical reactions,

Figure 2: Excerpt from "Milk Paint is Chemical Engineering"

physical and chemical separations, irreversibility, cost analysis, phase transitions, and alternative approaches to completing the same goal.

In the development of milk paint, participants are taught about what constitutes milk and the processes that go into separating the main proteins. Imagery combines nanostructure detail of milk, while depicting the irreversible chemical reaction that happens over time or with a deliberate pH change. Visuals incorporating commercial separators are included as a direct tie back to chemical engineering. Other concepts such as the cost analysis between alternative approaches include a depiction of a money scale to emphasize that overall cost incorporates both time and money.

The goal of the comic is to provide an additional experience that ties the reader to the event and the scientific concepts. The student-teacher dialogue creates the opportunity for readers to put themselves in the student's shoes and practice the skill of asking questions themselves. Additionally, the dialogue supports critical thinking by inviting readers to answer the questions themselves before reading onto the next panel or page. By implementing the narrative between the student and teacher, and including anecdotes of other chemical engineers, the comic is designed to pair moments in the demonstration with visual storytelling of making milk paint.

Methods & Demonstration

After the pre-event survey and discussion of research and consent, the facilitator presents the participants with the idea that "milk paint is chemical engineering". At this point, the study group receives the comic. Participants are welcome to read or flip through the comic alone, or join in a read-aloud session, up through the first few pages. When reaching the comic's second page, the facilitator begins the demo, following the scenes in the comic. The control group receives nothing. Two groups may occur anytime so long as there are no overlapping participants.

Figure 3: Participant Paintings from Study

The demo proceeds following the comic step by step protocol, while the facilitator asks guiding questions with emphasis on chemical engineering concepts along the way. Comic readers are encouraged to use the comic as a guide to answer some questions, while the control group has no supplemented information. As the milk paint demo reaches phase separation, participants are welcome to volunteer with steps in the protocol. When the demo concludes (milk becomes paint), all participants are invited to mix paint colors of their own and receive medium to paint on. Participants are welcome to paint or ask any questions as the session begins to wrap up. Before dismissal, participants complete the final survey.

Preliminary Results

This study was conducted in multiple locations while determining which methods of survey worked best for the population of interest. Online surveys were significantly less fruitful than paper, in-person surveys. The results presented here review the initial trial incorporating in-person paper surveys with variable survey completion. It was observed that inclusion of incomplete data sets (missing questions) did not have an impact on the overall findings. Missing sets were normalized to the number of questions answered, to reflect a comparable value. There were no more than 33% of questions missing for all data sets used. In total, there are 10 participants from the control group and 5 participants in the study group, with age ranges between 8 and 11.

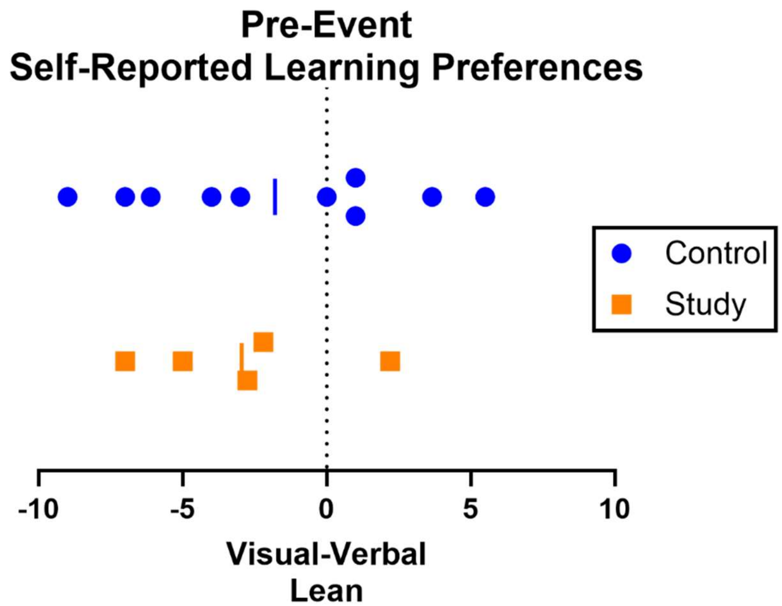

Figure 4: Learning Preferences. The vertical line signifies the mean score. Calculated based on results from the visual and verbal section in Felder Solomon's Index of Learning Styles. Data are collected from the initial trial with 10 control participants and 5 study participants.

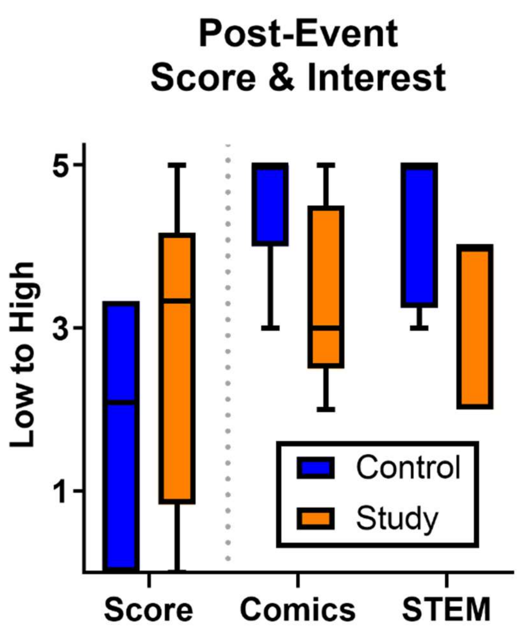

Figure 5: Post-Event Survey Results. Score & Interest reflect the participants final score on the quiz specific to the chemical engineering concepts involved in milk paint. This is also shown alongside their self-rated interest in comics and STEM. Data are collected from the initial trial with 10 control participants and 5 study participants.

The spread of participants on the visual-verbal scale between the study groups remains consistent, with no statistical differences. Figure 3 depicts a larger range of individual scores in the control group, which can be expected with the larger sample size. Despite low numbers limiting the statistical analysis, these group populations reflect a variety of learning preferences, a promising contribution for further studies. There were no findings that visual or verbal learners performed differently regardless of which study group they were a part of, though this may change with more data and trials.

While there are differences in understanding scores these are not significant alone or considering motivation. It is possible that because this study group leans towards visual preferences, comics may be visually appealing, but not necessarily supportive of learning through text. It is also noted that this study is run informally through a camp program, and participants may be more eager to interact with the drawing material rather than sit and read. While comics are discussed together, participants may find filling surveys and spending time reading less interesting than painting and chatting with other study participants. A point of interest from the study group had arrived with a lower overall interest in STEM (Fig. 7), however they slightly outplaced the participants in the control group in their understanding. This could support that comics may support learners who are less interested in STEM than those with high interest. This would be an interesting finding which will be considered when running future studies.

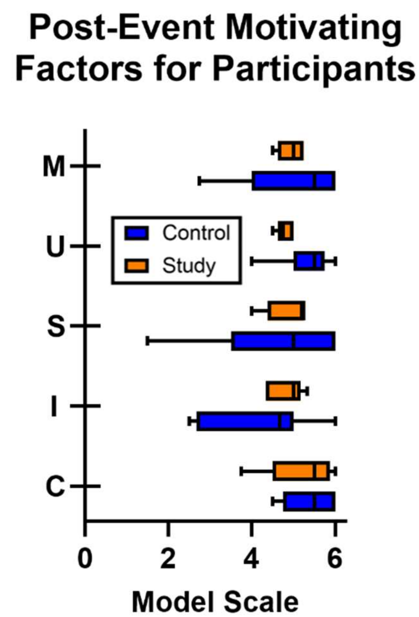

Figure 6: Post-Event Motivating Factors for Participants. The scale and model are adapted from Brett Jones. Data are collected from the initial trial with 10 control participants and 5 study participants.

This initial trial shows little difference across motivating principles. Though nearly all participants scored highly, the wider spread indicated in the control group may clue to other findings in a larger data set. We could hypothesize that participants in the control group may report motivation with greater variance than the study group. Such a result could suggest that comics have a stabilizing effect on participant motivation.

It is essential to run further trials to evaluate a more diverse study population, reaching more verbal leaning learners. With a limited number of participants, this work only represents a small population in the K-12 space. It is expected that with a larger group, there may be more interest in joining a group in reading the comic together, opposed to being distracted by other participants. This creates a new consideration for this study regarding group size influencing score or motivation. Additionally, this interactive demo alone can spur increased interest in the chemical engineering concepts, outweighing the effects of science comics on interest, though this might not be reflected in understanding of the material. Regardless, data from this study suggests that more trials are necessary to consider whether understanding of concepts (quiz score) correlates with learning preferences or motivation.

Strategies & Pitfalls

Adjustments made to the IRB per trial ensured that data could be collected in a reasonable and respectful manner. Paper surveys yield data for preliminary results and inform the next steps, where previous online survey platforms and timelines suffered from participant outreach and parental collaboration. Some challenges remain logistical, however, supplementing this study with an ongoing scheduled program at local Boys and Girls Clubs helped streamline time blocking and avoid participant overlaps. By aligning sign up and using established lines of communication for parental consent (vacation camp sign up containing study consent), participants could be easily filtered into groups without penalty, joining other groups if not receiving consent or voluntarily exiting the study.

It is possible that bias may influence survey results in comic and STEM interest, as these questions occur in the post-event survey. As study participants are exposed to the Milk Paint comic and control groups are not, the control group reflects their interest in their perception and experience of comics and STEM, while the study group reflects this interest in addition to the experience of the event. To account for possible differences, STEM interest was gauged in both surveys, and there are no significant differences, suggesting the event and comics does not deter participants. To avoid this possible pitfall in the future, these questions can be moved to the first, pre-event survey.

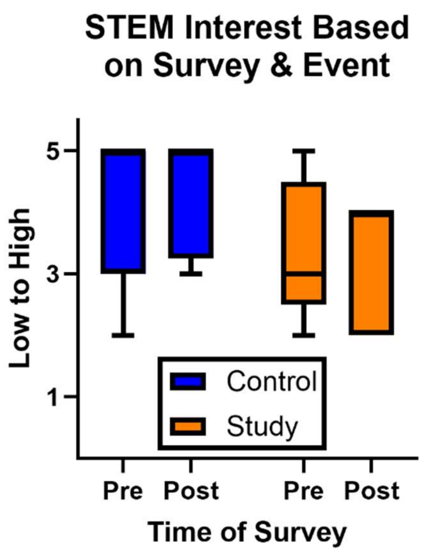

Figure 7: Differences in Responses for STEM Interest based on when the question was surveyed.

A final option could include a video recording of the study to replace the burden of filling out surveys with counting raised hands votes, or more facilitating students collecting question-and-answer responses. Surveys as a method of data collection may be more valuable in formal learning assessments compared to the one presented here.

Next Steps

We expect to reach out again to Boys and Girls Clubs or other youth community centers to continue incorporating this study as a STEAM block in their summer camp or other established programming. Upon collection of data, analysis will be run via established methods [16], in conjunction with initial trial data. Other data collected includes gender, age, and race, and with a larger data pool it may be possible to incorporate assessment on STEAM interest and engagement with more population specific variables.

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