Using Student Developed Comics to Promote Learning of Transport Phenomena Concepts

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Anecdotal evidence indicates that current undergraduate engineering students spend numerous hours per week reading popular science-based Internet comics, such as xkcd.com and phdcomics.com, for example. Thus, it makes sense that comics can be leveraged as a learning modality for engineering students. The use of comics in STEM education is not new, however, they have yet to be utilized extensively in higher education to teach engineering. Having taught a senior level mass transport course numerous times, a common challenge for students that persists is applying mathematical concepts to describe binary diffusion. Thus, here we will present the implementation of a project in which teams of students developed comic books with a goal of deriving and explaining the most general form of Fick's first law of diffusion to an average freshman chemical engineering student. This was piloted in a senior level chemical engineering mass transport course, and is also currently be conducted in an elective transport phenomena course. Initial feedback from students was positive, revealing a desire to be creative and explore complex engineering topics from a unique perspective.

visual literacy and learning

The education of young children often begins in picture books where pages are filled with light-hearted illustrations, and somewhere within the same space, equally prevalent, is a single word or a simple sentence that describes the imagery. In this way, children learn how to connect an idea, based on perception, with language. Early childhood instructors mimic this form of learning by using visuals to teach concepts. However, by the time students reach middle school, these visuals are minimized or altogether discarded in favor of a canon that sublimates print literacy to a grand, almost mythological status. In this context, language is objectified—devoid of perception or imagery and stripped down to an entity that can assist the human brain in memorization and reasoning yet lacks visual data to fully aid the brain in observation, comprehension, and interpretation.

According to Harvey J. Graff [1], educators perpetuate the misconception that, as other forms of visual media—Facebook, Youtube, Instagram, film, TV—increase in presence, illiteracy also increases. College instructors lament students' underdeveloped writing abilities and their poor reading comprehension while watching them rapidly absorb and comment on content from a handful of online articles on their mobile devices. On the one hand, students struggle to comprehend college-level texts, yet, on the other hand, they can quickly consume information through videos, memes, list articles, and numerous other resources around the globe. Cary Gillenwater [2] asserts that the overemphasis on the importance of print literacy inhibits recent generations of students from connecting to not only the content of a course but to the instructor as well.

effects of visual illiteracy

Many educators have discovered that the perceived epidemic of "illiteracy" isn't due to a lack of textbooks and traditional printed literature but, rather, due to a lack of visual media in the classroom. Students aren't necessarily less literate; they are simply more literate in ways that are linked to technology, pop culture, and the visual world. Some educators, therefore, have turned

to using comics to increase students' visual literacy, which, as Sean P. Connors states, is "the ability to interpret (read) and produce (write) images" [3]. While many teachers understand the importance of visual literacy, and they may even recognize the utilitarian aspects of comic books, visual literacy is largely overlooked in education [3]. The 21st century made its debut as a globalized world unlike any other in the past, in which visual media—expressed through fragments of information from music videos, television shows, Instagram photos, and internet communities—influences the structure of the brain. "The range of media adolescents use to represent their thoughts and experiences, and the ease with which they are able to synthesize word and image using digital technologies, has led some educators to argue that the ability to communicate effectively in the 21st century entails 'multiliteracies'" [3]. Recognizing the significance of perceiving images and the lines, shapes, and forms that make up an image as individual expressions of thought is conducive to one's ability to navigate the current workforce and social world. After all, being able to read the graphic symbols on a cell phone is now arguably as important as being able to read one's own language. Comics, particularly when used to teach students to explore how an idea is being expressed, are closely linked to how the human brain processes and produces information: through a combination of language and images.

using comics as teaching tools

Comics, however, have struggled to achieve the amount of scholastic consideration that other artistic and literary works have garnered for several reasons. One is the medium's connection to the juvenile. As mentioned above, young children are educated through picture books with simplistic messages, and it's difficult for people to ignore the popular stereotype of an adult male reading comics in the basement of his parents. Historically, comics were made to be accessible to a wide audience, including those who could not read [4]. James Buckey Carter, in his essay "Comics, the Canon, and the Classroom," even goes so far as to suggest that the preference for traditional notions of literacy—the ability to read and write—is connected to racism, classism, and ethnocentrism [5]. Marginalized groups have been, and to some extent still are, frequently discouraged from reading and writing; therefore, literacy has become associated with financial stability and academic success despite that people of color, women, and the impoverished classes have faced numerous other barriers, in addition to illiteracy, that have obstructed their upward mobility in society. Furthermore, indigenous cultures, the frequent targets of racism, colonization, and imperialism, emphasize oral/verbal literacy and visual symbols over written language. This idealization of literacy as a primary determinant of achievement and intelligence grew out of, in part, from racist Western perspectives on violated, colonized groups [1]. While it is obvious that most educators today are not using print literacy to exclude or alienate marginalized groups, the emphasis on this particular ideology surrounding literacy came about partly as a result of archaic and outmoded perspectives on education that still persist in subtle ways. It is not the norm, for instance, for graphic novels to be included on course reading lists, nor is it common for a course to require the use of "graphic textbooks" to disseminate information.

Comics, with their simple, easily accessible syntax and cartoony art forms, are consequently perceived as low-brow for their universal appeal and lack of elitism. Despite these perceptions, comics have been integrated into the scholastic world, not as merely a hybrid of art and literature, but as a legitimate and unique medium for human expression. Art museums now seek and host exhibitions featuring famous comics, several peer-reviewed journals, such as the

International Journal of Comic Art, specialize solely in the study of comics, and popular novelists, such as Neil Gaiman, collaborate with comic artists to produce bestselling graphic novels.

But why teach visual literacy with comics, specifically? Comics are deeply layered with regards to their benefits. Art educator Rachel Williams states that, on purely a pragmatic level, comics are less expensive than other school resources, and students are not intimidated by them [4]. This is especially important for multilingual students as well as non-traditional students who may be "out of practice" academically or are first-generation college attendees. Comics also encourage students to examine a palimpsest (a term used in visual art to describe a work that both reveals and obscures multiple layers of visual information). of components, including the relationship between image and text, the interaction between the reader and characters, the presentation of the content, the arrangement of visual information, etc. "These texts do not dictate what students notice first, how or what they 'read,'" says Williams. "Like scanning a work of art, the reader can decide where to begin and how long to look" [4].

Unlike children's picture books, the relationship between image and text found in a comic is complex and sophisticated, requiring the reader to interact with the material in a way that other image/text relationships do not [2]. While children's books are didactic in that they tell the reader what to think and how to interpret the image/text relationship, the effectiveness of a comic partly depends on the reader's ability to draw conclusions about the content based on the often somewhat ambiguous interaction between the visual action within the frame and the text's meaning. In other words, the combination of text with imagery that (generally) references the implied meaning of the words involves the reader as a participant rather than as merely an observant.

visual literacy and creativity in engineering

It is now widely recognized that it is necessary for engineers to not only have a solid foundation in technical skills, but also "soft" skills, such as communication (written and oral) and teamwork. Thus, it is important for current engineering students to be trained to communicate complex scientific concepts to various audiences, including those without scientific backgrounds [6]. An effective way to do this is through interesting/creative visuals that can be generated through software, for example. Therefore, engineers must now be able to translate and convey technical concepts to a cohesive visual story via images. Researchers have unequivocally demonstrated that, "making visualizations is integral to scientific thinking" [7]. This requires another "soft" skill that has more recently garnered massive amounts of attention and resources – creativity [8][9]. This stems from the complexity of societal challenges/problems that we now face that require creative, innovative solutions. Engineering is problem solving, and problem solving requires creativity. However, creativity is not a skill that is often nourished in traditional engineering curriculums. Students typically do not have the chance to express themselves in any other forums besides performing calculations, analyzing data and applying theories and equations. In fact, engineering students indicated, through survey results, that their educational experiences lack 9 of the *10 Maxims of Creativity* [10]. Therefore, it is critically important to hone/develop this skill in engineering students to prepare them to tackle the global, interdisciplinary challenges our society currently faces. The United States (US) was ranked 1st in innovation until 2008 and as of 2015 World Economic Forum ranks the US at 4th [11]. In an attempt to close the innovation gap, STEAM (Science, Technology, Engineering, Art,

Mathematics) has become a prevalent acronym in not only secondary education, but also in higher education. The House of Representatives introduced a joint resolution in 2012 stating that, "adding art and design into Federal programs that target the STEM fields encourages innovation and economic growth in the United States" [12]. The Rhode Island School of Design (RISD) has been at the forefront of this movement and has developed a STEM to STEAM program to transform educational policies and encourage the integration of art and STEM to promote innovation. Many of the companies that hire engineering graduates in the New England region value not only fundamental engineering skills, but also creativity as evidenced by a quote from the CEO of United Technologies, George David: "We are a company founded on innovation and believe the arts, like science and engineering, both inspire us and challenge our notions of impossibility" [13]. With potential engineering employers seeking graduates who are not just technically competent, providing them with a learning environment in which they can be creative and integrate the arts is of critical importance.

using comics to teach engineering

Recently, comics and graphic novels have emerged as tool to teach engineering concepts as well as provide an avenue for students to hone their creativity. They have been used in the chemical engineering field [14] with successful preliminary results and more widely in a first year engineering graphics course [15] and a computer software course [16]. However, they have rarely been student generated or developed [17], which does not allow students to exhibit their creativity and improve visual literacy skills.

student developed comics for learning transport phenomena

In an attempt to foster creativity and visual literacy, 78 senior chemical engineering students were tasked with developing their own comic book to describe Fick's law of diffusion to the average freshman chemical engineering student. This particular topic was chosen because it was observed during previous years of teaching mass transport that students faced challenges when connecting mathematics they learned in previous courses to applied chemical engineering concepts. This pilot was funded by an internal grant so that students could print hard copies of their comic books and distribute them to the freshmen students. 17 comic books were generated by teams of 4 – 5 students. More recently, senior students enrolled in an elective chemical engineering advanced transport phenomena course have been tasked with developing comics on a specific industrial application of transport phenomena. The deliverables/steps to student comic book generation are shown below:

(1) Selection of topic and genre (e.g., horror, comedy, romance)
(2) Plot Synopsis (brief summary of the story – 1 paragraph) and Script (for 10 pages) whole group.
(3) Character Designs – person 1 and person 2.
(4) Pencil Sketches – whole group.
(5) Inks – person 3 and person 4 and Lettering – whole group.
(6) Final comic.

To ensure all students contribute to the comic, they must initial the pages that they draw. The only rule is that no stick figures are allowed. Some students are not comfortable with drawing, so digital resources, such as [18] are also provided. Character designs (shown in Figure 1) are next,

done by two, or all of the team members, followed by pencil sketches, completed by the entire group. Lastly, inks and lettering are the final steps performed by half and all of the group, respectively. The comic books are required to be 10 pages (front and back) with 4 panels each (example page shown in Figure 2). Before each assignment was due, rubrics were provided to students along with examples and resources, so the students had an idea of what was expected. The vast majority of student received above grades of B for their final grades for the comic. Most expended a large amount of effort to make the comics. The grading criteria for the final comic is given below:

Content/Research 40/40

- Is the comic's topic well researched and accurate?
- Is the information coherently presented?

Craft 25/25

- Did students effectively incorporate the presented techniques and processes involved in creating their comic?
- For example, did the students designed characters that correspond to the comic's themes or content? or the students created a sensible and logically-ordered visual narrative to support their ideas as opposed to one that lacks structure?

Aesthetics 10/10

- Did the students create a comic that is visually or conceptually engaging?
- Is the comic demonstrative of the effort students put into the project?

Completion 25/25

- Did the students complete the project and the entire process from start to finish?

qualitative/anecdotal responses

In general, the qualitative feedback regarding the generation of comics was positive from both senior and freshmen students. One senior student said, “This was a really nice break from doing the normal calculations and derivations. It got me to use my brain in a different way.” Other teams indicated they enjoyed the humorous aspects, making comics that playfully mocked other students or faculty or coming up with clever/unique ways to present the material so that freshmen students would be entertained. Freshmen who the instructor spoke with were excited to come get their comic books and see what the seniors had created. In the future, a rigorous study on the impact of the comics on the students will be conducted. Most of the senior groups were asking when their printed comics would be available, so they could share them with family and friends. As this was a pilot, the instructor was just implementing it without obtaining quantitative data to see if this was even a possible activity to use in the future. This semester, however, quantitative data will be collected, although only for 11 students, through the use of surveys.

lessons learned and conclusions

Some lessons learned from the piloting of this project include: (1) more thorough grading of the initial stages of the construction of the comics (2) enforcement of course content requirements (i.e., the comic must convey technical information) (3) printing of final comics ASAP, before the end of the semester and (4) rigorously assess student learning outcomes in relation to student developed comics. Due to the positive feedback from students in this initial

pilot, the instructor is encouraged to continue this effort in other courses and to perform more rigorous studies on various aspects of student learning in the future.

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Figure Captions

Figure 1: Example of character sketches/designs.
Figure 2: Example of a page from a student generated comic

Table Captions
Table 1: Examples of student incorporation of Fick's law concepts into comic book topics and genres.

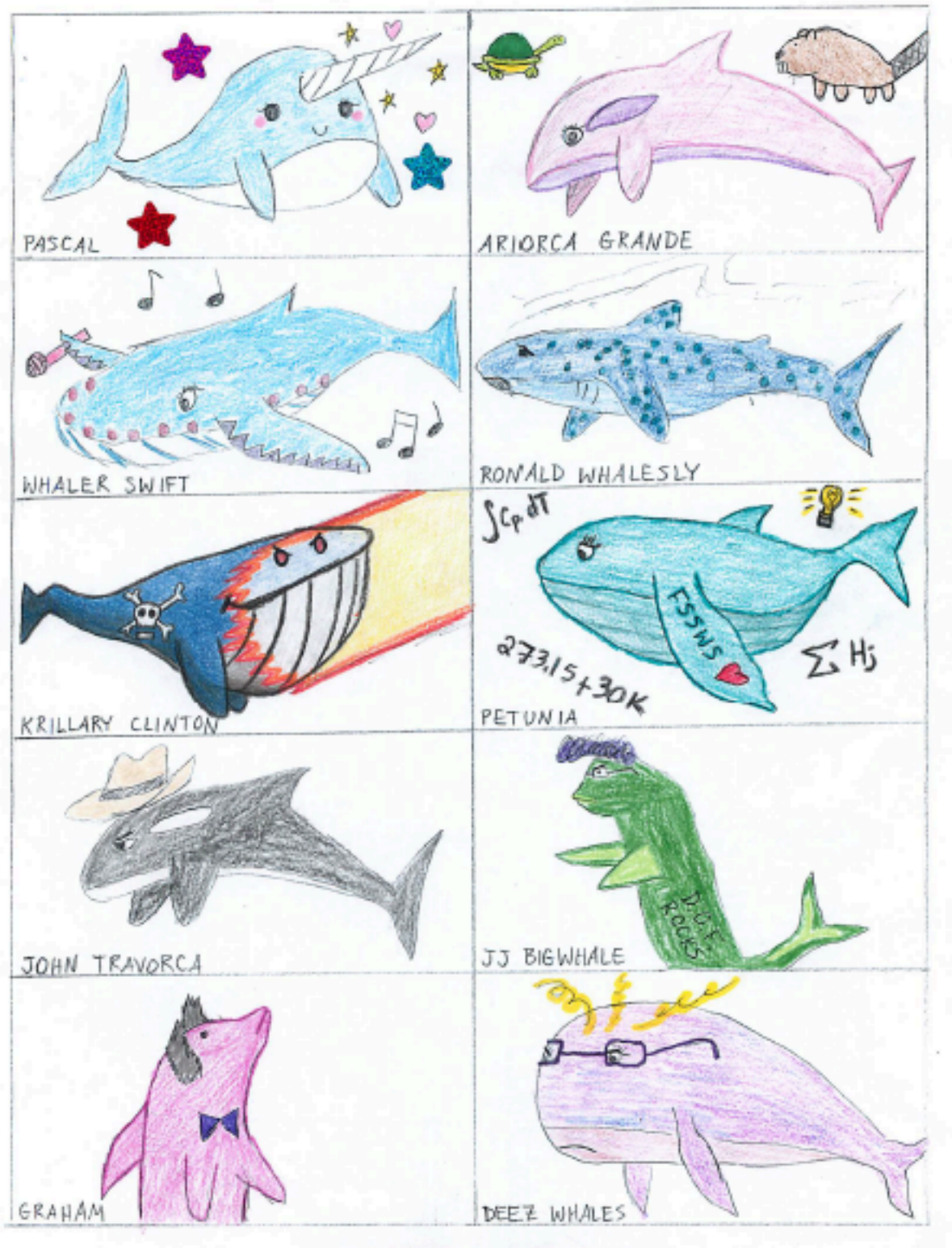
PASCAL
ARIORCA GRANDE
WHALER SWIFT
RONALD WHALESLY
KRILLARY CLINTON
PETUNIA
FSSWS
JOHN TRAVORCA
JJ BIGWHALE
GRAHAM
DEEZ WHALES

Figure 1


MAXIMUS the FEARLESS LEADER
VICTORY
POWER OFF
MAN STAN! YOU GOTTA HEAR ABOUT MY DREAM! IT WAS WICKED!
WE CAN TALK AFTER CLASS MAX. YOU REALLY NEED TO CHECK OUT WHAT WE ARE DISCUSSING. WE SCALED UP FROM MOLECULAR TO MICROSCOPIC - BROWNIAN MOTION TO DIFFUSION!
CHARLIE!
SCALING? WE AREN'T TALKING ABOUT THE SOCCER BALL MODEL ARE WE?
IT STILL LOOKS LESS EXHILARATING THAN THE LAST PICTURE I SAW ON THE BOARD.
NAH.
HIGH CONC
LOW CONC

Figure 2

Table 1

Genre	Incorporation of Class Concepts
Comedy	Pirates and rum production - diffusion of Carucas seed into rum
Romance	Blobs Sherwood and Darcy diffusing through a tunnel on their way to work in search of true love
Comedy	A group of whales wages a war to retrieve Graham's research by using mass transport to stop a diffusing wave of antimatter
Action	Diffusion Man must stop convectionator from stealing Concentration Gradient Boy and using his powers to control people with his bulk motion
Action	Max falls asleep during mass transport and dreams he is a Roman warrior who must use Brownian motion to defeat an evil army

Appendix: Comic Book Assignment

Project – Comic Books
The goal of this project is to do a bit of research (in teams of 3 – 4 people) and find a research paper or book that relates transport phenomena to one or more chemical engineering industrial systems and review and present it in the format of a comic book. The idea is that the comic will illustrate the topic to the average junior or senior chemical engineering student. Examples of papers/books below. If you choose a book, find one topic that you want to study.

- A.S. Jonsson, R. Wimmerstedt, A.C. Harrysson, "Membrane distillation — A theoretical study of evaporation through microporous membranes"
- B Sundén, M Faghri. "Transport Phenomena in Fuel Cells," 2005.
- J Bear, JM Buchlin, "Modelling and Applications of Transport Phenomena in Porous Media," 1991.
- Norbert Kockmann, "Transport phenomena in micro process engineering"
- SC George, S Thomas, "Transport Phenomena Through Polymeric Systems"

Your final grade will consist of several assessments:

Deliverables:
Selection of topic from paper or book, comic genre and get my approval. **Due: Friday, February 3rd** (10%)
Plot Synopsis (brief summary of the story – 1 paragraph) and Script (for 10 page - examples will be posted on HuskyCT) – whole group. **Due: Friday, February 24th** (15%)
Character Designs – person 1 and person 2. **Due: Friday, March 24th** (20%)
Pencil Sketches[1] – whole group. **Due: Friday, March 24th** (20%)
Inks – person 3 and person 4 and Lettering – whole group. **Due: Friday, April 14th**
Final comic. **Due: Friday, April 28th** (35%)

Overall Assessment

Content/Research 40/40
- Is the comic's topic well researched and accurate?
- Is the information coherently presented?

Craft 25/25
- Did students effectively incorporate the presented techniques and processes involved in creating their comic?
- For example, did the students designed characters that correspond to the comic's themes or content? or the students created a sensible and logically-ordered visual narrative to support their ideas as opposed to one that lacks structure?

Aesthetics 10/10

[1] For the pencil sketches of the entire comic, each person in the group can draw a frame and sign with their initials at the bottom right hand corner of the frame to ensure that every group member participates in the creation of the comic.

- Did the students create a comic that is visually or conceptually engaging?
- Is the comic demonstrative of the effort students put into the project?

Completion 25/25

- Did the students complete the project and the entire process from start to finish?

Rubrics including teammate (anonymous) and self-assessment will be distributed beforehand for each deliverable.

Comic Synopsis Rubric

Criterion	<60	70	80	90	>90
At least 1 page – double spaced, 12 pt font					
1 paragraph beginning					
1 paragraph middle					
1 paragraph end					
Main character descriptions					
Genre and synopsis match					
Description of when					
Description of where					
Description of who					
Description of what					
Description of how					

Comic Script Rubric

Criterion	<60	70	80	90	>90
At least 3 pages – double spaced, 12 pt font					
Title					
Character Notes					
Art Notes					
8-10 pages describing panels for each					
Relevance to Mass Transfer					