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Integrating Comics Into Engineering Education To Promote Student Interest, Confidence, and Understanding

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Abstract

The use of comics as an educational teaching tool is a practice that has existed for several decades but only recently begun to be utilized in STEM fields. The dramatic expansion in STEM comics through independent artists, book series, and video animation has illustrated the opportunity for the integration of art into STEM to improve educational approaches. Despite a continued general perception that comics are 'childish', comics have a unique and demonstrated potential for improving student enthusiasm, confidence, and understanding in complex concepts.

The use of comics directly addresses one of the major obstacles to effective learning in chemical engineering education, in that many core concepts have an abstract nature with no obvious visual representation (such as fugacity) or have such complexity that the visual depiction is crucial for student understanding (such as thermodynamic cycles). Examples of real-world applications, demonstrations and experimentation can often help to facilitate learning, but presenting a visual learning tool that students can frequently return to can help make the concepts less abstract and more comprehensible. Further, by depicting characters that students can directly identify with, and utilizing dialogue that includes common questions asked by students, comics provide an opportunity for further engagement that other teaching tools do not have.

In several chemical engineering courses at Northeastern University, comics have been integrated into courses to help facilitate improvement in student interest, confidence, and comprehension. Comics were produced in collaboration with professional artists as well as comics developed by the students

themselves in their classes. Analyses of the impact of the comics has indicated a substantial improvement in student interest and confidence, while student understanding has either held steady or also improved depending on how the comics were integrated into the courses. This paper will discuss the development of these comics, different methods for implementing comics into courses, and the impact of the comics on student learning experience.

Note: A preliminary version of this paper was printed in the proceedings of an ASEE regional conference.[57] This paper has been greatly expanded in the discussion of the background and previous work, and includes analysis of several additional comics.

Background

Chemical engineering can be a difficult major for any student, given the complexity of the core concepts and frequency with which the subject matter can be highly theoretical. This challenge is particularly difficult to address as an instructor, given the breadth of fields within chemical engineering, and the resulting range in depth of mastery that each student will need upon graduating. These challenges are similar to those facing current education in STEM (science, technology, engineering, math), in particular the theoretical nature of some core concepts. Traditional approaches to support instruction, and establish connection between concepts and applications, include providing examples of real-world applications, demonstrations, and/or hands-on experimentation. However, some concepts' depth and complexity can cause all traditional attempts to be unsuccessful, particularly for concepts without obvious visual representation such as fugacity, and given the non-visual nature of equations.[1]

Improving and broadening visual instruction is beneficial for learners beyond those with a perceived inclination for visual learning. Studies have shown combining text with images improves retention of the information,[2,3] and students can better transfer the gained knowledge towards solving problems when the instruction is delivered through a multimedia presentation of concepts.[4] In order to improve chemical engineering instruction, developing better visual instruction and learning techniques will help better communicate the concepts to students and more thoroughly engage them with the information.[5-7] While some visual techniques are commonly used in chemical engineering education, including McCabe-Thiele diagrams to help explain vapor-liquid equilibrium in distillation columns and phase diagrams as a visual foundation for teaching cycles in thermodynamics, there remains room for improvement of visual techniques in many other areas of chemical engineering education.

This paper will discuss how the use of comics as a novel teaching tool offers a potential opportunity to promote student confidence and understanding of the more difficult concepts present in chemical engineering education. Comics can provide a means to combine visual media and text, as well as create a visual presentation for complex theory and equations. Comics by their nature are a graphic depiction interspliced with text to construct a full narrative, and provide multiple means of visual instruction, including depicting dialogue between characters, as well as captions with graphic art, charts, and plots. Through their educational use in chemical engineering, complex concepts like fugacity, uncertainty, and PID controls, among others, can be presented in an interdisciplinary novel manner with which students can directly connect.[8]

It should be noted that comics can be defined as a series of sequential images, arranged in a distinct order to tell a story or deliver information. Comics can involve text or be presented as strictly visual images, as fits the purpose of delivering the story or information. Comics are thus distinct from single panels, sometimes referred to as cartoons, which will focus on a single moment or idea within its image. Comics are somewhat similar to infographics, which stylishly present information on one central topic with some integration of visuals and text, but comics have the flexibility to be longer, can encompass more ideas and complexity, and are less reliant on the amount of textual content compared to the visual content. Comics also are still images, as compared to animation or videos with moving images.[8] This paper will focus strictly on comics as compared to these other visual forms of media.

The use of comics also helps provide an instructional tool to unify the differences that may exist in classroom instruction. Class sizes have increased in many universities with the increase in number of chemical engineering students, as the total number of chemical engineering bachelor's degrees awarded nationwide has more than doubled from 2007 to 2015;[9,10] at Northeastern University, this growth has occurred at an even faster rate, with the total population of chemical engineering undergraduate students across all years of education increasing from 283 students in 2012 to 587 in 2016. At Northeastern, this growth has led to multiple sections of most courses being offered each semester, many of which are taught by different instructors, which in itself leads to a range in teaching styles and learning achievement. Other factors can contribute to variations in instruction from section to section or from semester to semester, including different numbers of TAs or tutors for each course depending on available funding. By providing a comic with more interactivity and visual emphasis than a textbook, this teaching tool allows for more consistency in instruction across the sections.

In addition, a majority of chemical engineering students at Northeastern have claimed a preference for visual learning tools as compared to verbal learning tools. As presented in Figure 1, several sections of different courses were asked to rate their preferences for different learning tools on a scale of 1 to 9, with 1 representing strictly visual approaches and 9 representing strictly verbal approaches, and values in-between representing a mix of teaching approaches. Across several courses and grade levels, students expressed a greater preference for visual tools than text-based instruction. While some studies are inconclusive on the evidence for visual learning as a specific trait,[11] the students' self-assessed desire for visual learning tools have opened the potential for comics to directly fill a perceived need.

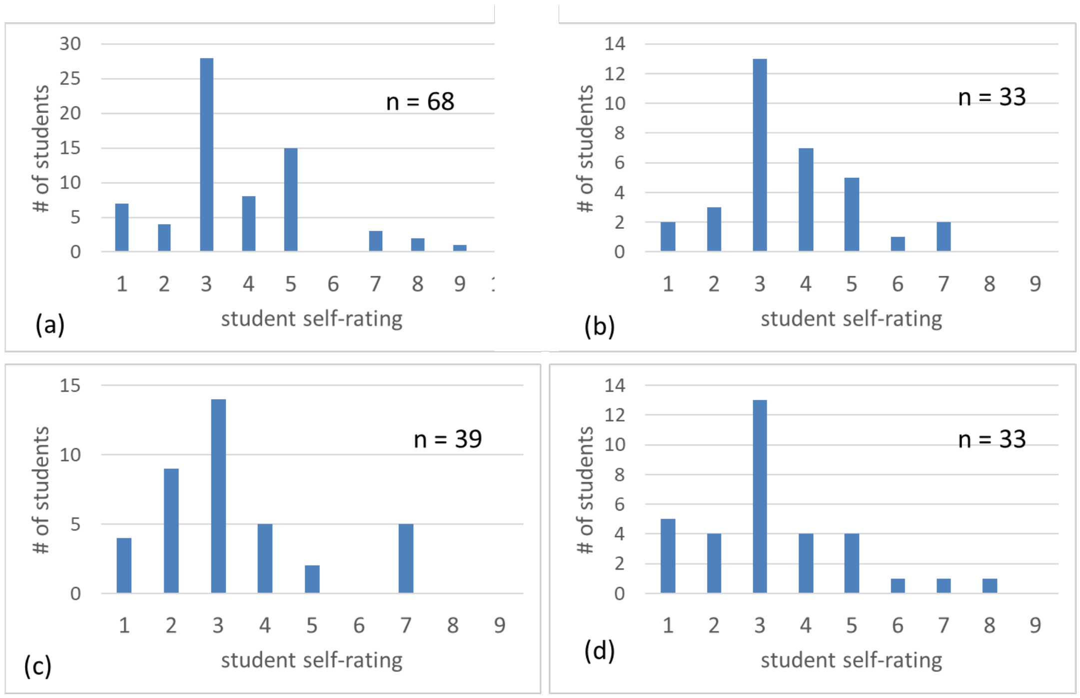


Figure 1. Results from survey of several student chemical engineering sections at Northeastern, with students rating their learning preferences for types of learning tools, 1 representing strictly visual tools and 9 representing strictly verbal tools. Data were taken in sections of (a) third-year students in Thermodynamics II, (b) fifth-year students in Process Control, and (c and d) fourth-year students in Transport II.

Through collaboration with professional and student artists, short comics that provide supporting instruction in chemical engineering can be provided directly to students to help promote their confidence and understanding in the subject matter. These science comics have been distributed in several core classes in the chemical engineering curriculum and have now been adopted or used by over 50 different colleges, high schools, companies, and government organizations in the United States, as well as in the U.K., Belgium, and Denmark. This paper will discuss the production of the comics as well as begin to assess their effectiveness.

Previous work

The use of comics as a learning tool dates back to the 1940s, when their potential impact in any field of education was observed soon after the first traditional comic book was published in 1933.[12] Driven by 95 percent of all 8-14 year-olds and 65 percent of 15-18 year-olds reading comics by the 1940s,[13] significant research into the potential of comics followed. Initial studies focused on using comics to expand vocabulary and reading comprehension,[13-16] but researchers determined that comics as a medium had potential in almost every subject.[17] Despite these highly encouraging conclusions, social backlash to comics in education, led by Fredric Wertham and his book *The Seduction of the Innocent*, claimed that comics promoted illiteracy, violence, racial stereotypes, and homosexuality, among other factors.[18] Wertham's testimony to the U.S. Senate Subcommittee to Investigate Juvenile Delinquency in 1954 effectively ended further studies on comics in education for nearly 50 years.[19] Any current views of comics as 'childish' and inappropriate for educational use essentially persist from Wertham's efforts in the 1950s.[20-24] Until some comics began to receive significant awards and recognitions in the 1990s, little research was conducted with comics in education, with a few studies in the 2000s helping to encourage further integration of comics into classrooms.[12]

In recent years, the production of comics for educational purposes has seen significant growth, with particular focus on STEM fields in the last 10 years. The success of graphic novel series like "Science Comics" has highlighted the potential of integrating comics into STEM education. Comics have been implemented in classrooms to help explain medical techniques,[25-26] describe solar-terrestrial environment such as global warming and geomagnetism,[22] and improve student attitudes and understanding of biology.[27] Science comics have addressed synthetic biology,[28] nature,[29] polymeric science,[30] mathematics,[31] and a wide range of other scientific disciplines. However, this growth has not previously carried over into chemical engineering. Thus, comics, if effectively written, drawn, implemented and utilized, could have similar potential for instruction in chemical engineering.

A few recent studies have also suggested that STEM comics may promote engagement, confidence, and understanding. Spiegel et al. integrated biology-focused comics in 9th and 10th grade classrooms, and found students who read the comics as opposed to reading an essay were 4.82 times more likely to be engaged and want to read more learning materials; further, the researchers found no knowledge difference between the groups that read the comics versus reading the essays, suggesting that the comics were just as beneficial in promoting understanding as traditional methods.[32] Wylie and Neely implemented comics into Science, Technology, and Society lectures at the University of Virginia, and determined that undergraduate students who received the lectures with comics remembered more of the concepts discussed than students who received lectures without comics.[33] Kim et al. investigated the use of anatomy comics across a range of ages in formal learning structures, and also determined that the comics promoted interest and understanding.[34] As to informal learning, Amaral et al. used comics on stem cells in outreach programs along with illustrated newspaper chronicles, radio interviews, and animated videos, and 46 percent of the outreach participants pointed to the comics as having the largest impact on their understanding.[35] Thus, previous research suggests comics have the potential to promote interest, confidence, and understanding in STEM concepts.

Some of the current interest in using comics in STEM education stems from the desired progression to STEAM (science, technology, engineering, art, mathematics). The United States was ranked first in innovation until 2008, and was ranked fourth by the 2015 World Economic Forum.[36] STEAM has become a prevalent acronym in secondary and higher education as a result of working to address the innovation gap. A joint resolution from the US House of Representatives in 2012 stated that, "adding art and design into Federal programs that target the STEM fields encourages innovation and economic growth in the United States".[37,38] An alternative approach to simply balancing the arts with STEM is to enhance and promote STEM learning by integrating the strengths and visual nature of the arts. While STEAM approaches can include co-teaching, creative problem-solving, or hands-on design/construction activities,[39-42] comics use an art-driven STEM learning approach while establishing both interdisciplinary learning and creation. STEAM approaches can also extend to chemical engineering.

This use of comics does still need to overcome the previously-discussed perception from society as a whole, and from some older instructors, as being merely a means of entertainment or simply a 'childish' or 'fringe' approach to STEM education,[20,21] even with the potential counterpoint in considering the seriousness of political cartoons. Unfortunately, this societal perception persists despite students' significant interest in learning STEM concepts from comics as observed from sales of graphic novels about science.[22] There are a number of benefits to using comics, however, that can further promote their use in chemical engineering instruction. First, comics are less expensive than many other educational resources, and second, learners are not intimidated by them.[43] Third, the comics create a visual component to students' notes that allows for instruction to be more readily revisited, particularly if the comics depict interactions between an instructor and students, and if dialogue between the characters integrates common questions that students would ask in relation to the concept. In effect, this depiction helps to recreate not only the information that was presented, but the instruction itself. Fourth, studies have shown that students will better engage with the information if presented in a comic as opposed to an essay (in this case, meaning several paragraphs of text), and will have a greater desire to continue reading instructive material when presented in a comic.[32] Finally, comics serve to encourage readers and learners to examine a broader set of layers of information at a time, including the relationship between image and text, the interaction between the reader and characters, the presentation of the content, and the arrangement of visual information.[44] In visual art, this term is a "palimpsest" of components, used to describe a work that both reveals and obscures multiple layers of visual information.[43] For educational purposes, the reader is more involved as a participant rather than as merely an observer, as the combination of text with imagery is supported with the visuals generally referencing the implied meaning of the words.

Despite growth of comics as STEM learning tools, however, most studies investigating the use or effectiveness of comics in undergraduate education have not focused beyond introductory classes.[45] Given the success observed in using comics as teaching tools at other levels, the potential exists for improving student confidence and understanding in higher level classes. This paper discusses efforts to integrate comics into both introductory and higher level chemical engineering courses.

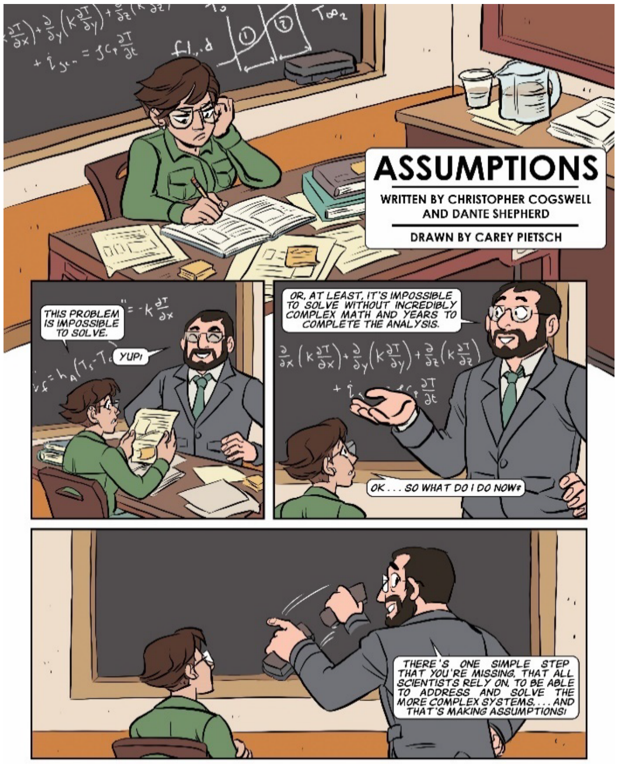
Methods

Nine different comics have been produced in collaboration with professional and student artists for use as supplemental instruction in a chemical engineering course. These comics were developed to address specific concepts in specific courses that students had previously experienced difficulty with. Each comic was written to depict a discussion between a professor and students, or to illustrate direct instruction being delivered by a professor, with the purpose of disseminating course concepts and to visually re-create lessons or discussions that students could return to at a later time.

All comics were written by either a professor or graduate student with some previous experience in the specific comic's subject matter. The completed scripts included minimal storyboarding, with scenes and characters described and blocked out, and dialogue written. Final work was only completed after consulting with the artists to fine-tune and maximize the integration of the visual depiction and the conceptual text. Artists were paid on commission at a per-page-rate for their work through the grant or federal work-study. The majority of collaborating artists were professionals who had expressed interest in the research and were selected by the writer; one student artist was a chemical engineering student working to complete a minor in art and animation. All drawings were designed to be as expressive as possible, with the purpose of holding the students' interest and facilitating more engagement between the reader and the content.

Depictions of different characters were often left to the artists to decide, except for in a few cases where the artist was asked to draw characters similar to certain instructors; these instructors had previously taught the course that would use the comic, and the goal was thus to draw a stronger connection between the classroom instruction and the use of the comic as a teaching tool. (To date, none of the depicted instructors have taught the course at the same time that the comic has been used, although students have noticed and appreciated the illustrated depictions.)

Several comics focused on general engineering knowledge and skills, including "Uncertainty",[46] "Data Analysis",[47] and "Assumptions"[48], with the objective to be used in Unit Operations Laboratory courses. More specific concepts from core chemical engineering courses include "Recycle/Purge Streams"[49] for the Conservation Principles (Mass and Energy Balances) course, "Refrigeration Cycles"[50] for Thermodynamics I, "Heat Exchangers"[51] for Transport II, "Fugacity"[52] for Thermodynamics II, and "PID Controls"[53] for Process Controls. Topics from related elective courses have include "Gene Therapy"[54]. Individual pages from two of the comics are presented in Figure 2.



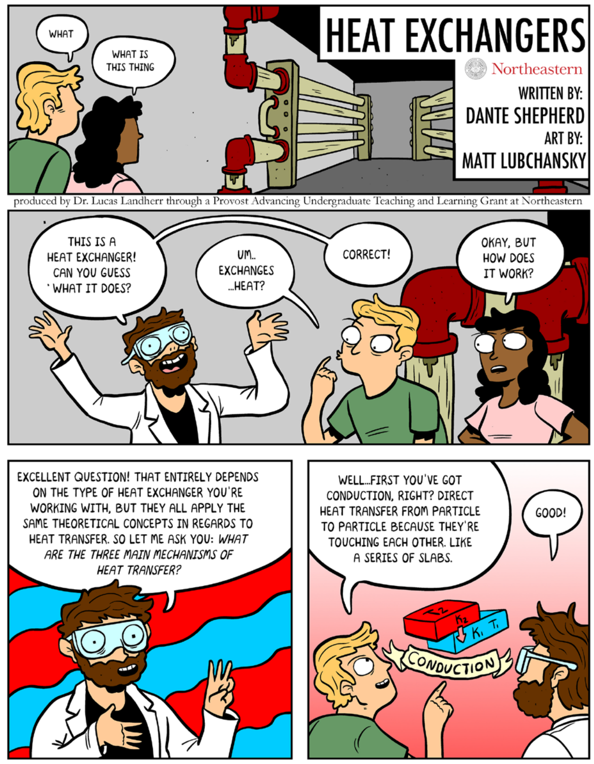


Figure 2a, 2b. Page 1 of 10 of "Assumptions" comic,[48] and page 1 of 6 of "Heat Exchangers" comic.[51]

Comics were distributed in the corresponding classes as printed, double-sided copies provided to each student. Each comic was only given to the students after the comic's subject matter had been introduced and discussed in class; thus, the comics were used to reinforce the initial instruction and discussion in class as opposed to replacing the discussion overall. The purpose in providing the comics as supplemental instruction was to provide reinforcement of the course instruction, to reassure students who might be reluctant to learn from comics, and to encourage use of the comics by other instructors.

Comics were also made freely available online, for use by any school or institution,[55] with word-of-mouth through social media and conference presentations being the primary means of enabling their integration into courses beyond Northeastern University.[56] Educators and employees at different institutions and companies contacted the authors to either request permission to use the comics, or to comment on how the comics had been used, allowing for an approximate tracking of the use of the comics by other individuals. The effective dissemination into classrooms and courses at more than 50 learning institutions and companies indicates a clear interest and demand for comics when they can be effective innovative learning tools.

Experience and Assessment

This paper will specifically focus on the experiences in implementing several comics and assessing their impact on student engagement, confidence and understanding. All comics discussed can be accessed and used for free by anyone.[55]

"Uncertainty"[46] and "Data Analysis"[47] Comics Experiences and Assessment

In general, students responded positively to the comics, finding them enjoyable to read and use. In several sections over two years of Transport Laboratory I, students repeatedly cited the "Data Analysis" and "Uncertainty" comics in for their laboratory reports based on the documentation and explanation of certain principles and equations. The uncertainty propagation equations presented in the "Uncertainty" comic were a common point of reference, reinforcing the potential of a comic visual approach even to equations. In an anonymous survey, students were asked to comment on the implementation of the comics and their usefulness; students' positive comments to the "Uncertainty" comic included:

- "Hard topic to explain, the comic alone might not make you an expert but it does a great job explaining the idea and helping students feel more comfortable with an abstract idea"
- "(a) way of making the subject less stressful and (more) joyful"
- "The comic was very helpful. Made what usually seems confusing very clear."

Students' positive comments to the "Data Analysis" comic as previously reported included:[57]

- "Helpful, descriptive, not intimidating"
- "Would be good for younger students just starting to learn about data analysis"

Negative responses and comments primarily focused on the amount of text in comparison to the amount of art ("could be text-heavy at times"). These comments were minimal but correctly recognized that a balance between the visual depiction and the verbal description should be achieved before a comic is implemented as a teaching tool.

Students also responded to a 1-5 Likert scale survey (with 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). In response to questions asking "Do you feel that this science comic is/was helpful?" and "Would you recommend this comic to other students?", 16 of the 17 survey responses agreed or strongly agreed that the comic was helpful; the only other response was neutral. In addition, all of the students agreed or strongly agreed in recommending the comic to other students. The 17 responses came from a class of 19 students, and were not likely to be biased towards certain responses given their broad range of academic ability and experiences.

Students were asked on a similar 1-5 Likert scale (with 1 = no confidence and 5 = very confident) to assess their confidence in the subject matter before reading the comics and after reading the comics. As previously reported, 53 percent of students expressed no to mid-level confidence (ratings of 1-3) before reading the comics; after reading the comics, 94 percent of students were relatively to very confident (ratings of 4 or 5) after reading the comic. These results are presented in Figure 3.

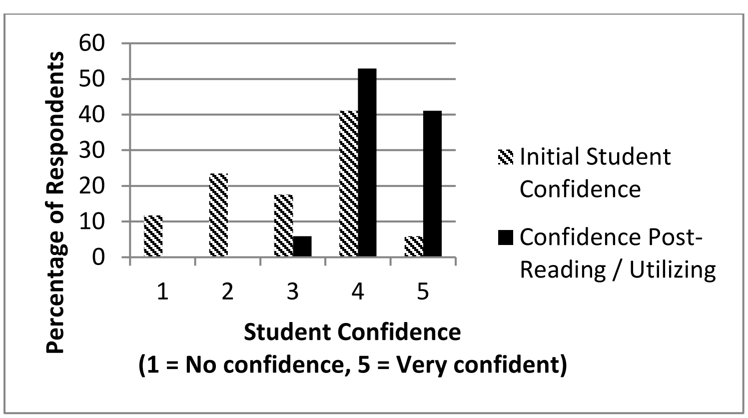


Figure 3. Student self-assessment survey responses (n = 17) before and after reading the "Data Analysis" and "Uncertainty" comics in a Transport I Laboratory course, as previously reported and reprinted with permission of ASEE.[57]

In order to assess student understanding, students finished the Transport Laboratory I course with a design project, for which they developed an experimental proposal to address one of the National Academy of Engineering's Grand Challenges. For their proposed study, students were required to determine a purpose, design an experiment and analysis, and describe their plan for limiting measurement uncertainty. This proposal was submitted as a written report evaluated by the instructor.

The instructor compared the final reports in the Fall 2015 semester to those evaluated by the instructor in previous iterations of the course with similar class sizes. Some improvement in student performance was observed in these comparisons. Overall, the average grade for the assignment increased from 83.0 ± 1.6 to 86.2 ± 1.2. This score was compiled from several individual components evaluated on a scale of 1 to 10, including the objectives' 'scope of experiment', which increased from an average rating of 8.0 ± 2.1 to 9.4 ± 0.1. The overall grade indicates small but marked improvement in student performance, complementing the substantial improvement in student confidence in the subject matter.

"Feedback Controls" Comic[53] Experiences and Assessment

Analysis was also conducted with respect to the "Feedback Controls" comic, which depicted the individual PID tuning parameters proportional gain (K_C), integral time (τ_I), and derivative time (τ_D) as boxers, with the strength and speed of their punches relating to the impact that the respective tuning parameters would have. An instructor who had taught a section of Process Controls in both the fall and spring of the 2014-2015 academic year, implemented the comic in a section of both semesters in the

2015-2016 academic year. A similar exam question was given to students in all four semesters that directly addressed the effects of the individual PID tuning parameters.

Class sizes varied, as reflective of the growth in the enrolled students at Northeastern (10 students in fall 2014 to 17 in fall 2015; 36 in spring 2015 to 55 in spring 2016). Average student scores did improve when the comic was implemented and provided to students in the 2015-2016 academic year. On the exam question, the average score improved from 60.0 percent to 79.4 percent in the fall semesters with the smaller classes, while the score improved from 70.8 percent to 77.5 percent in the spring semesters with the larger classes. These results were not statistically significant, but suggest that further evaluation with larger sample sizes may provide further insight.

"Fugacity" Comic[52] *Experiences and Assessment*

In order for the comics to be an effective teaching tool for any instructor, it is of course necessary for them to be effective when used not just by an instructor who collaborated on the production of the comic but also by other teachers. The results of these findings are more mixed.

In implementing the comic, effort has occasionally been necessary to overcome some instructors' perception of comics as being 'childish', as directly quoted from another instructor; these instructors most commonly share traits of being older and already having taught throughout a long career. When sharing the potential use of the comics at conferences and with some faculty directly, a few older instructors have directly challenged the potential of comics as a teaching tool, specifically citing their age and experience and thus reluctance to trying something that was markedly different. It is unknown if such unwillingness similarly extends to other more recent teaching approaches, including active learning and flipped classrooms.

It is possible that an instructor who provides the students with the comics but does not present the comics with clear support of them as a teaching tool, may affect the potential effectiveness of the comics. In one informal study conducted with a Thermodynamics II class in the spring 2017 semester, approximately 60 students were instructed for three weeks on the concept of fugacity, and then given an in-class problem set of 10 AIChE Warehouse conceptest problems focusing on fugacity. The following day, students were given the comic to read as an assignment that night, and then were given the same 10 conceptest questions in class the next day. While the instructor was supportive of attempting this assessment, students later commented that the instructor seemed somewhat dismissive of the potential helpfulness of the comic.

As part of a post-survey conducted with the second iteration of the conceptest questions, students were asked to conduct a self-assessment of their confidence and understanding in the concept of fugacity, as well as whether or not they felt the comic was beneficial as a teaching tool. Student were asked to rate their responses to the questions on a 1-4 Likert scale, with 1 representing 'strongly disagree', and 4 representing 'strongly agree', with the student responses depicted in Figure 4. From the approximately 60 responses, 89 percent of students agreed that the comic was helpful to their understanding of fugacity, and 88 percent felt more confident in their understanding; further, 95 percent of the students felt the comic should be recommended to other students. These results were certainly positive, particularly with respect to a notoriously difficult concept like fugacity.

The conceptest results indicated no significant statistical difference in student understanding from before reading the comic to after reading the comic. Even after dividing the student responses into subsets based on a self-assessment of how much they preferred visual learning tools compared to verbal learning tools, the concept data were inconclusive. However, one major impact from implementing the comic was determined. Because students responded positively to the comics and had a higher selfreported confidence in working with the concept of fugacity, the instructor completely reversed their opinion of using the comic in the classroom, with consideration of the potential to integrate its concept-driven focus to support their mathematical-driven approach in the class. The instructor has now enthusiastically adopted its use in future iterations of the course. Students in the current spring 2018 semester section have commented how much they enjoyed the "Fugacity" comic, and the instructor observed a 20-point improvement on the overall exam average related to the topic compared to student performance in the Fall 2017 iteration of the course. These trends are extremely positive, in respect to both student and instructor response, and need to be evaluated further.

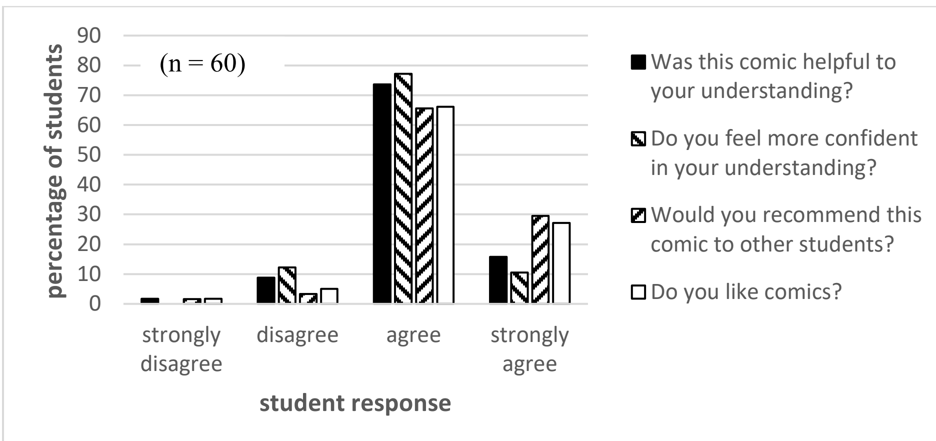


Figure 4. Student self-assessment data after reading the "Fugacity" comic in a Thermodynamics II class.

"Gene Therapy" Comic[54] Experiences

In addition to the comics directly developed for chemical engineering undergraduate courses, a "Gene Therapy" comic was written and drawn by an undergraduate team of students, with the intention for it to be used as part of K-12 outreach and in undergraduate elective courses. To measure the comic's broader educational potential, a survey was posted on social media requesting open participation from general public, to which 510 anonymous individuals agreed to take part. Each respondent was asked to share their level of education and rate their understanding of the concept of gene therapy on a 1-5 Likert scale (with 1 = None, 2 = Minimal, 3 = Average, 4 = Good, and 5 = Excellent). Each respondent was then asked to read the comic, and then reassess their understanding. These assessment results are presented in Figure 5. Alternative means of distributing the information, such as videos or demonstrations, were not tested for comparison; current work by the students in developing a K-12 module that would incorporate an experiment or be presented in a video form would allow for further evaluation.

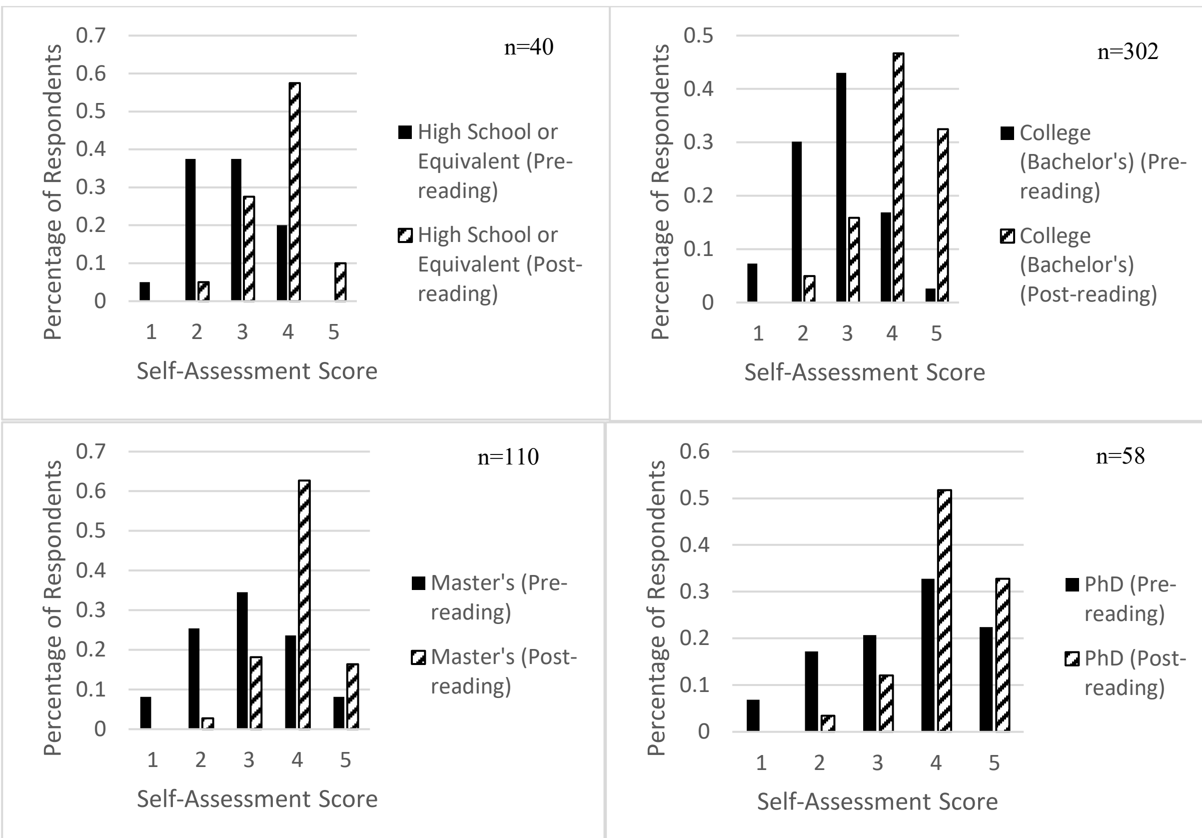


Figure 5 a-d. Pre- and post-survey self-assessment results for the "Gene Therapy" comic, differentiated by the respondents' reported highest or current level of education.

The results indicate a clear improvement in self-assessed understanding of the concept of gene therapy after reading the comic. Perhaps more significantly, 99.4 percent of the 510 respondents agreed when asked if they found the comic helpful, and 98.8 percent of the respondents agreed when asked if they would recommend to others science comics like the "Gene Therapy" comic as a learning tool.

Further study into long-term comprehension and the comic's effectiveness when fully integrated into a classroom study remains unknown and requires additional analysis.

Further Attempts at Investigation

While using these comics in the classroom, it has been difficult to conduct proper assessment of their effectiveness in providing them to one section of a course while using the other section for control group purposes. Because the comics are striking, not just visually but also in terms of being a learning tool used as in a chemical engineering classroom, students have repeatedly talked about the comics with their classmates in other sections. These discussions led to requests from the control group students for the comics, as well as complaints that they had not been provided the comics, which then necessitated sharing the comics with them as well and thus eliminating the control groups. These failed control group studies happened on several occasions, and as such is requiring similar studies investigations to be conducted externally with students at other universities. However, this in itself is a positive development, as it indicates that many students had interest in using comics in their courses as well as had a positive enough experience in the comics to encourage classmates to read them.

Recommended Practices

As the comics are not meant to replace but only supplement instruction, in their use as an additional learning tool, there are potentially a number of means by which comics can be effectively incorporated into a course. Current investigation, in collaboration with instructors from other institutions, is underway to develop an overall working model by which any instructor can develop and implement comics of their own. While this future work still requires more thorough study, there are a few recommendations that can be made at this point.

First, students need to be specifically directed towards the comics with a digital link in an assignment or handout, or provided a physical print-out of the comic. Different instructors at Northeastern have used different means of providing the comics to their students, with mixed results in whether the comics were actually read or not (as reported by students at the end of the course). Including the comics in coursework documentation as suggested reading materials, for example, or simply included on a course website with other course material, will not be enough of an impetus for most students to seek out the comics, thus resulting in minimal if any benefit to the overall class. A hard copy has additional benefits, as students will insert it into their classroom notes and can thus return to the comics for additional support when reviewing a related lecture. Similarly, providing the comics to students in a course where they can potentially be cited in a report will further increase the likelihood that the comics will be thoroughly read and considered.

Second, as evidenced by experiences with the “Fugacity” comic, the instructor should openly approach the comics’ potential use with positivity, encouraging the students to follow through on reading the comics if they believe it will be of benefit. The instructor presenting their belief that the comics can be helpful is critical to ensure the students are encouraged to be thorough in reading them and thus best appreciate the concepts presented.

Finally, with respect to developing the comics themselves, it is important to remember that art is not bounded by reality, meaning that any analogy or comparison that can be depicted visually is possible to be presented through these learning tool. Comics can use any medium in the base art, from drawings to graphic design to photographs, and initial results have indicated that thee quality of the art appears to be less important than the integration of the art itself with text to effectively present the comics. The comics produced so far have relied on a range of artistic styles, different stories and humor, and varying degrees of color or black-and-white, but students have responded with consistent positivity to their use as a learning tool. Further investigation is necessary to confirm this result, but the potential impact of comics on student interest, confidence, and understanding may simply rely on the comics' existence and integration into the course, and not the overall artistic quality of the product itself.

Conclusions

The development of comics as supplemental teaching tools has significant potential in helping students gain a greater confidence in complex concepts as well promoting student understanding. By integrating discussion of difficult topics with a visual presentation, comics provide a means of supporting and reinforcing classroom instruction. While results have been mixed on whether student understanding is improved, students have clearly expressed improved confidence in the subject matter after reading the comics. Instructors thus have a novel means of helping students better engage with complex topics.

Many questions remain open and need to be evaluated further, including how implementation of the comic by the instructor affect the comic's impact, how the comics can best be integrated into courses, and what type of concepts and topics are best-suited to be the focus of comics. Further assessment will help determine appropriate implementation models for different classrooms; future plans also include developing a working model that other instructors and artists can follow for their own production of comics.

Acknowledgments

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* - Dante Shepherd is the pseudonym for the author, Lucas Landherr, in much of his creative work.

Note: It is common in references for comics for (w) to refer to the writer and (p) to refer to the artist, when the writer and artist are not the same individual.