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By Students For Students: Using Course Projects To Create Learning Materials For Future Classes

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Abstract

In order to improve student understanding of course concepts, as well as to increase the range of learning material available for students, a course contribution project was introduced in a heat and mass transfer course. This project required students to find potentially fun and effective means to communicate topics related to the course subject matter, with the project deliverables providing new learning tools that could be used to help other students learn.

Students were given several potential project types to select from: writing sample exam problems, for which both problem statements and solutions were required; producing a 5-minute video; writing and drawing a 10-page comic; or developing an experimental module that could be replicated by other students. Students also developed their own original projects, including computer simulations and board games. All of the projects were required to focus on concepts related to heat and/or mass transfer that were addressed in the course, including conduction, convection, heat exchangers, and separations equipment. The intended audience for each project output was the students' classmates, essentially meaning any student in the course.

With the permission of the students who completed the project, the deliverables were shared with students who took the course in the following semesters, thus providing new learning tools and conceptual explanations to supplement instruction by the professor. Over the course of five semesters, 174 projects were completed by 283 students, with a range of project types completed.

After introducing the course project and then subsequently providing the learning material to future classes, students both reported and were observed to have benefitted from the projects as additional learning tools. In terms of having worked on the project themselves, at least 84 percent of students felt working on the project helped them better understand specific course concepts, and at least 94 percent felt the project helped them to better communicate chemical engineering concepts. Students were also surveyed about projects provided for their learning that were produced by students in previous semesters. At least 92 percent of students claimed to have reviewed the projects produced by previous iterations of students, and at least 84 percent reported that the previous projects helped to improve their understanding. Further, student performance on exams improved over the course of several semesters as the previous projects were integrated into the course as additional learning tools.

Assessment of the projects over several semesters, as both a deliverable by students and a learning tool for students, will be further discussed in this paper.

Introduction

At Northeastern University, the transport course focusing on heat and mass transfer is one of the most theoretically dense courses in Chemical Engineering. This course must first re-introduce the general concept of transport and draw connections to the students' learning of momentum transport, which for many of them occurred in a class they took a whole year previously. Heat transfer instruction must cover conduction, convection and radiation, as well as fins, boundary layer theory, heat exchangers, boiling, and condensation. Mass transfer instruction must cover diffusive and convective transfer through both Fick's Law and absolute flux, as well as begin to introduce separations. In a fourteen-week course that meets at most for about 41 hours of in-class contact time, this presents a demanding amount of course material to be taught in a limited amount of time. With class sizes fluctuating from 19 to 60 students, unique approaches are necessary to ensure that students are provided with the education they need.

Mid-semester evaluations were conducted each semester, for which students were asked to provide feedback in several areas, including positives, meaning aspects of the course they felt were going well or that they liked; deltas, meaning aspects of the course they felt would be better if they were changed; and any larger questions about the course or subject matter that they wanted answers to. The student answers were compiled and shared with the class themselves for discussion and explanation.

In these mid-semester evaluations over the course of several semester of the course, students frequently requested additional learning material beyond the lectures, problem set assignments, and textbook readings. Students had broad requests in terms of the type of material, ranging from more problem set questions to practice with, more sample exam problems, more lecture hours, more textbook reading assignments, more in-class example problems, and more. All requests were essentially for optional material that would not be graded, but would provide more material for students to practice from.

Table 1. Analysis of student feedback in mid-semester evaluations.

Semester	# of students responding	Percent requesting more learning material
Spring 2016	35	37%
Fall 2016	49	61%
Spring 2017	38	39%
Fall 2017	74	39%
Spring 2018	37	49%

Several limitations existed to directly addressing the students' requests. In-class time was limited given the scope of the course, so additional in-class problems were not possible. Additional class time outside of scheduled course hours was also difficult, as most of the students have widely varying schedules and most would have difficulty making any scheduled recitation time. Providing additional problems was possible and was provided, but concerns about potentially overloading students or their expectations limited how many additional optional problems or reading should be given.

Both the requests and concerns led to a different possibility: could a project be introduced to create more learning material? Effectively, if students themselves were tasked with developing the additional learning material that was frequently requested, then future students would benefit from materials developed specifically for them by peers who would understand their learning preferences. If the project was well executed, then the students developing the material would also benefit from their efforts. This paper discusses a course contribution project designed to improve students' understanding of heat and mass transfer concepts, by requiring students to develop learning materials for future iterations of students. The project deliverables and student performances will be discussed.

Curriculum Contribution Project

A course project was introduced with several desired outcomes. First, students would complete a project to create additional learning materials, thus lowering the grade weighting on the exams and problem sets. Second, by effectively communicating course concepts through their project, the students would reinforce their own knowledge and benefit from their work. Third, the project itself would create approachable learning tools that students in following semesters of the course could benefit from. As it is known that significant learning can occur from the design and creation process itself, the potential benefit for the production of the learning material would extend not only to future students who would make use of them, but also to support the understanding of the students developing the projects themselves.[1-3]

The course contribution project initially provided the opportunity for students to produce one of four types of learning materials for the course:

- Exam questions: students could write three questions equivalent to an exam problem's level of difficulty, and provide detailed correct solutions. In solving a problem, one must recognize the underlying principles at the core of the scenario or problem statement, understand assumptions involved and applied, utilize mathematic skills with known theory and equations, and apply engineering analysis to integrate all aspects for a complete solution. To write an exam problem, similar skills must be exhibited, all while creating material that will serve to evaluate the skills of others.[4]
- Video: students could produce a five-minute video. A video can connect concepts presented to an emotional response, and help the viewer to better connect to the information, as well as ensure a mastery over the subject matter by the video creators themselves.[3] The videos could present a fictional scene or can be a personalized lecture; the videos could utilize elements of a range of genres – comedy, drama, silent, western, etc. - or utilize a more documentarian format; the videos could rely on some combination of music, graphics, and effects, or simply show individuals and a script.
- Comic: students could develop an eight-page comic using any artistic medium; Comics require a delicate balance between words and pictures so as to ensure that the final product does not represent either large figures with minimal captions or giant blocks of text with small picture inserts. However, done well, comics can present concepts, theories, and equations in a way that best reaches visual learners and restructures the information in a memorable visual lesson that can be readily returned to.[5-8]
- Experimental module: students could design and build a simple experiment that demonstrated a heat or mass transfer concept. When well-presented and executed, with clear objectives and an easy-to-follow procedure, an experiment serves as an exemplary learning tool. Even if the experiment was made into a demonstration that could be done by one person in front of others, the visualization still allows for many of the same benefits, along with the opportunity that the viewers could later attempt to perform the demonstration themselves.[9]

Students were provided with examples of each type of project based on the instructor's previous work, but were not encouraged to produce material of similar quality or content.

Students were also given the opportunity to propose a different type of project. After some successful alternative projects were submitted, other specified project options were added:

- Simulation: students could code or program a visual representation or a calculation tool with changeable parameters. Simulations help to connect theoretical concepts and applications to actual numerical values; by allowing for flexibility in the initial and operating conditions, learners are given a means of direct experience and manipulation of the concept.[2]

- Game: students could develop a playable board game. A good educational game can use elements of standard games to help provide learning opportunities while reinforcing knowledge: answering trivia while moving around a board; solving problems to be able to move onward; competing against other players or working collaboratively to solve a problem.[10]

All projects, regardless of type, were required to focus on a heat or mass transfer concept that would be addressed in the course. Suggested topics include conduction, convection, radiation, fins, boundary layer theory, heat exchangers, boiling and condensation, diffusive mass transfer, and convective mass transfer.

The project structure was established with semester-long self-selected groups of 1-4 students. Groups were limited to 1 person if completing an 'exam problems' project, and limited to 1-2 students for all other projects, unless the group could propose expanding the project parameters in such a way that would allow for a larger group size to be permissible, such as creating a 10 minute video instead of 5, thus making a 4 person group acceptable.

Students had intermediate deadlines throughout the 14-week semester, with a project proposal due three weeks into the semester, a project update due eight weeks into the semester, and the final project due twelve weeks into the semester. The intermediate deadlines were established to help ensure that students would develop a schedule plan to guide their progress throughout the semester, and to allow for the instructor to provide constructive feedback as needed.

Grading expectations were defined at the beginning of the semester when the project was assigned. Students were reassured that artistic quality was not a priority for any of the visually-inclined projects, as long as sufficient effort was put in. Examples of insufficient effort would include developing stick figure comics, or videos that could not be heard. In general, the clarity of the project's objective accounted for 10 percent of the project grade, originality of the project accounted for 20 percent, communication of concepts accounted for 30 percent, and technical content itself accounted for 40 percent. Students thus had some flexibility in being able to express themselves creatively, while also needing to clearly craft their project around teaching concepts from heat and mass transfer.

At the end of the semester, students were asked to fill out a form allowing for their project submission to be shared with others. Students could provide permission for their project to be shared with 1) other members of the current class, 2) students in future iterations of the course at Northeastern taught by the current instructor, 3) students in future iterations of the course taught by other instructors from Northeastern, and 4) anyone outside Northeastern. If permission was provided, their project could then be utilized in future semesters of the course as additional learning tools for those students.

The project accounted for 11-14 percent of the final course grade, based on adjustments over several semesters. This additionally helped to reduce the weight of the course exams on the final grade.

Results

As of the spring of 2020, the course contribution project has now been integrated into the heat and mass transfer course for five semesters. Varying numbers of students per class, and different project types being presented, led to a range of different numbers of groups and group sizes.

Table 2. Class and project sizes in the heat and mass transfer course, by semester.

	Fall 2017	Spring 2018	Fall 2018	Spring 2019	Fall 2019
Total Students	72	37	53	58	63
# Project Groups	50	30	26	35	33

A range of project types was completed by the students each semester, depending on what options were presented to them by the instructor, and what original project types they might propose. The "other" project type indicated in Table 3 was a group composing an original song describing heat transfer. The final quality of this project was low, and was not worth being provided to students in following semesters. All other alternative proposed projects have been adopted in some later semester as a presented project type.

Table 3. Number of projects per project type completed each semester. An 'x' refers to the project type not being permitted or presented as a standard option, while '*' refers to the project type being completed before being presented as a standard option.

	Fall 2017	Spring 2018	Fall 2018	Spring 2019	Fall 2019
Video	14	5	13	10	9
Comic	11	5	10	18	20
Exam Problems	20	17	x	x	x
Experimental Module	4	3	2	1	x
Simulation	X	X	1*	6	2
Game	X	X	x	1*	2*
Other	1	0	0	0	0

The six main types of final projects over five semesters had a range of quality and potential impact. While project types were provided as examples for students to focus on each semester, the list of project types was adjusted over time depending on the effort and quality of the submitted projects. Some project types were no longer listed as permitted options, while other types were added as standard options.

<u>Exam Problems</u>

Writing exam problems was one of the original conceits behind the course project, as the creation of additional problems would meet the student request for more examples to work through. However, while 46 percent of groups opted for this project type in the first two semesters of the project, the quality of the produced problems rapidly dropped off. Many of the problems produced in the second semester were slight variations on problems already found in the textbook or done in class, so that there appeared to be minimal effort put into developing them. While they may have had some benefit for students to work through, the benefit to the students creating them was questionable. This project type was no longer permitted after the second semester of the project.

One example of a three-problem exam problem project that received a high course grade and has been received well by students in later iterations of the class is presented in Figure 1.

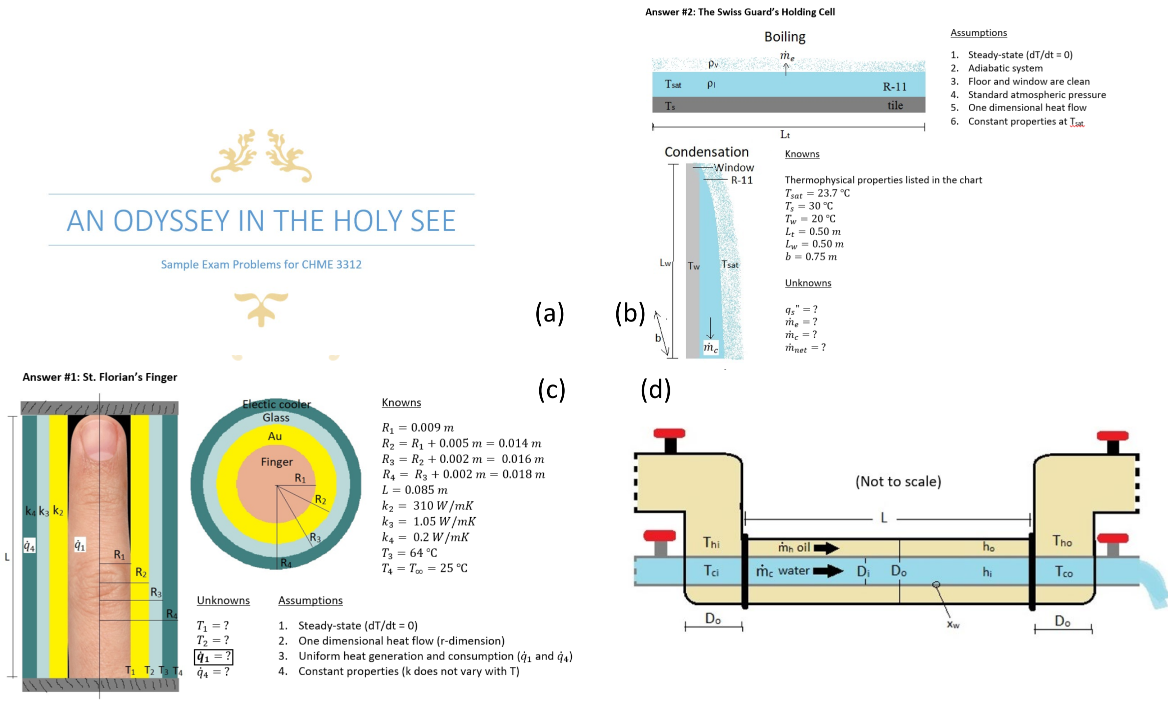

Figure 1. Example of an exam problem project, with (a) cover page for the story, (b) part of the solution for a condensation problem, (c) part of the solution for a composite wall problem, and (d) part of the solution for a heat exchanger problem. Larger images are available at sciencetheworld.com.

All exam problem projects required three separate questions; the project presented utilized a common storyline and developed problems around different course concepts of composite walls, condensation, and heat exchangers. Most exam problem projects did not approach the quality as presented in Figure 1. It is possible that the submitted problems could have been improved by requiring a common theme or story connecting all three exam problems, thus inducing more long-term planning and creativity from the students in the development of their project. The nature of three separate problems may have led some students to be less committed in their effort throughout the semester, compared to students working on other project types with semester-long plans for execution.

<u>Experimental Module</u>

While this project type was also well-intentioned, many students found it difficult to do, perhaps as a result of not fully grasping what the long-term impact of their project could be. A few groups developed operating procedures for experiments that they could not actually create, which would thus have also been difficult for later students to produce themselves. Other groups copied instructions of other experimental modules they had found and recreated the experiment, such as developing their own concentric tube heat exchanger out of basic pipes from a hardware store; while this project helped their particular understanding of the subject, the resulting project was not necessarily original. Only one group over four semesters developed a strong, original module that could be reproduced by other students. In that particular module, as depicted in Figure 2, food coloring in a water bath was heated from below to demonstrate mixing patterns and flow of free convection. After four semesters, given the limited quality of submitted projects, experimental module was removed as an option. It is possible that the quality of the experimental modules could have improved by providing a small budget for materials and requiring a demonstration of the module in practice; the lack of funding available and range of other project types already in place made it simpler to remove this project type instead.

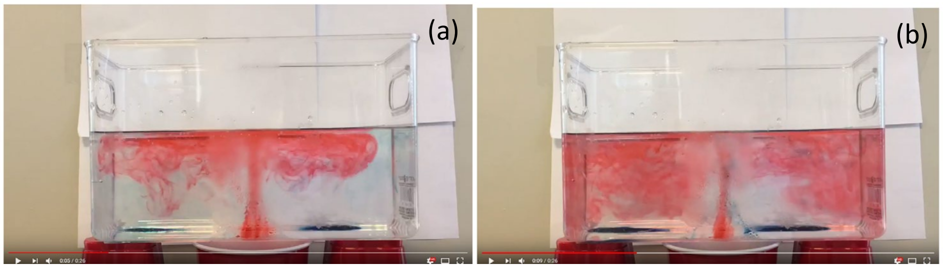

Figure 2. Screenshots from a video made with an experimental module demonstrating fluid movement in free convection.

<u>Video</u>

Videos accounted for nearly 30 percent of the 174 projects in the first five semesters of the project. Nearly all of the videos created have focused on some concepts from heat transfer; common themes involve using cooking to demonstrate conduction, convection, and/or radiation. Students have used a variety of styles to showcase their video, including stop animation, music videos, and solving problems on the board in front of a classroom. Most videos have not been voiceover descriptions of stock images explaining transport concepts, but instead students acting out roles from a written script. Screenshots from some of these videos are presented in Figure 3.

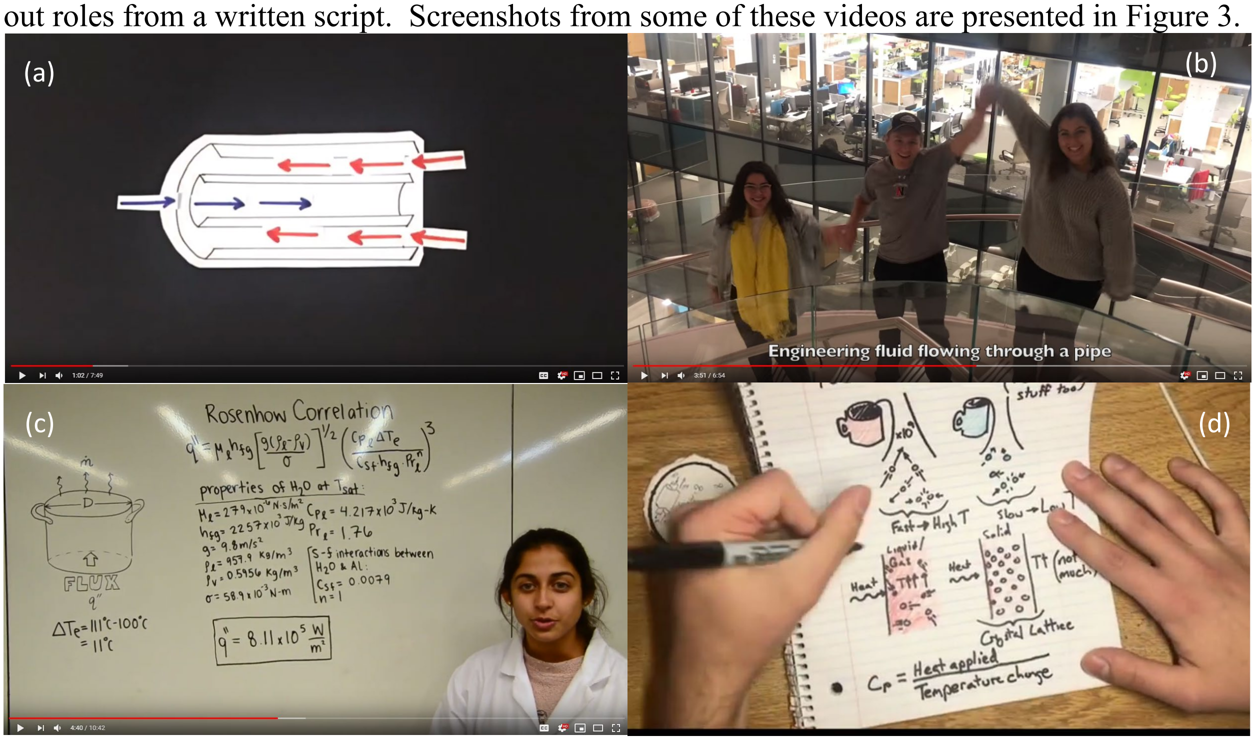

Figure 3. Screenshots of several video projects, including a) a stop animation film, b) a music video, c) problem-solving video, and d) an artistic voiceover. These videos are all available at sciencetheworld.com.

Comic

Comics have accounted for 36 percent of all projects produced, and 51 percent of projects after exam problems were removed as a project type option. Students have utilized a range of artistic styles in developing their comics, including hand-drawn art, photography, or digitally assembled figures as the basis for the medium of their comic. Most comics have utilized a story to help present the heat and mass transfer concepts, while a few comics have developed a style of an instructor lecturing directly to the reader.

Figure 4. Individual pages from several different comics projects, utilizing hand-drawn figures, photography, or digital pre-created tools to develop the visual medium, with content focusing on a range of heat or mass transfer concepts. These comics in full are available at sciencetheworld.com.

Simulation

The simulation project type was first proposed as an alternate project by a student in Fall 2018, and based on the success of their work, as depicted in Figure 5, was quickly adopted as a regular option for future semesters. The simulation was allowed to either create a visualization of general heat or mass transfer with some variability in parameters that users could interact with, or to conduct calculations for a series of variable parameters that would solve heat or mass transfer related scenarios. A main restriction was that the simulation needed to utilize software or coding programming that was readily accessible by the instructor and students, so that minimal downloading would be necessary before the user could interact with the program. Most of the groups that have completed a simulation project have used MatLAB or Python to create a calculation tool for heat transfer problems, with variable parameters including wall thickness, thermal conductivity, and temperature values.

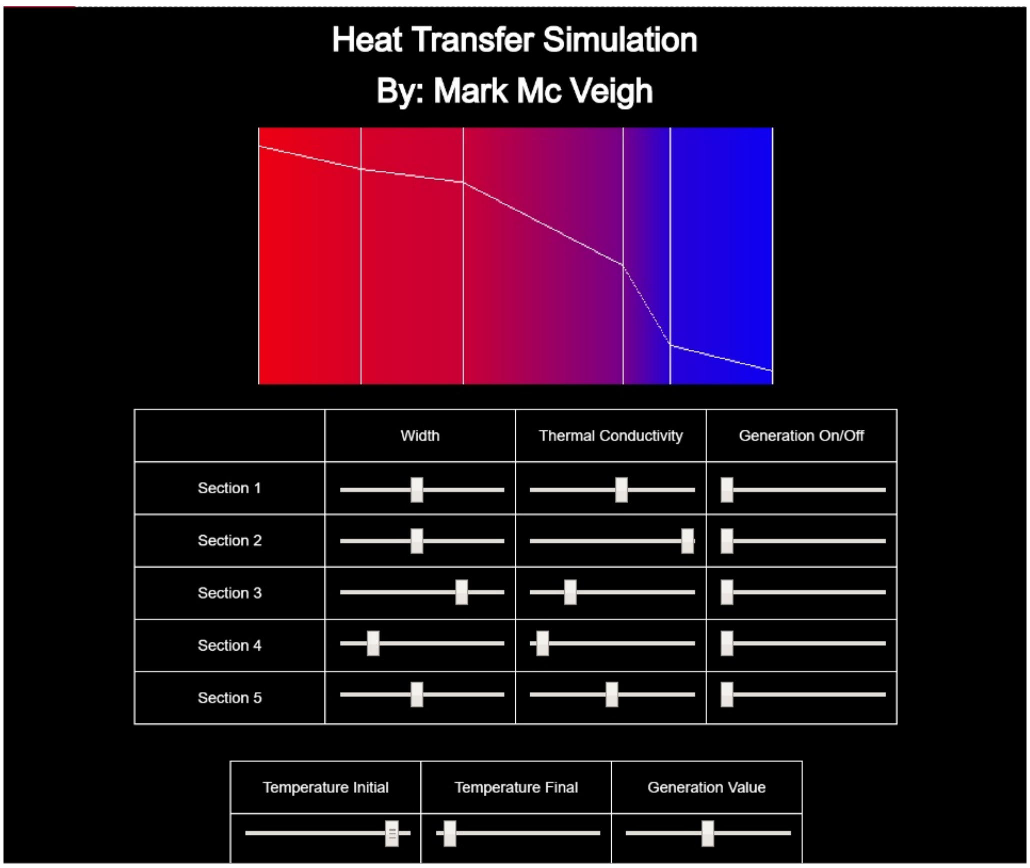

Figure 5. Screenshot of a composite walls simulation, with parameters determining width, thermal conductivity, generation, and temperature on sliders for user interaction. This simulation is available in full at sciencetheworld.com.

<u>Game</u>

After one group proposed making a heat transfer game as an alternative project type in Spring 2019, and two groups made their own heat transfer games in Fall 2019, a game-type project was formally included as a standard project type starting in Spring 2020. The games have taken on two different styles, either a conceptual trivia game in which players must answer questions to move forward; or a competitive game based around a heat transfer calculation, such as trying to get the lowest heat transfer rate while wall thickness, thermal conductivity, and temperatures can be changed.

The largest difficulty with the games has been that a single physical copy of the games was produced by each group, so that it is not a project that can be readily distributed for all students to play and learn from. Some current students have suggested that they will be attempting to develop digital versions of their games, which would allow for broader use in the future.

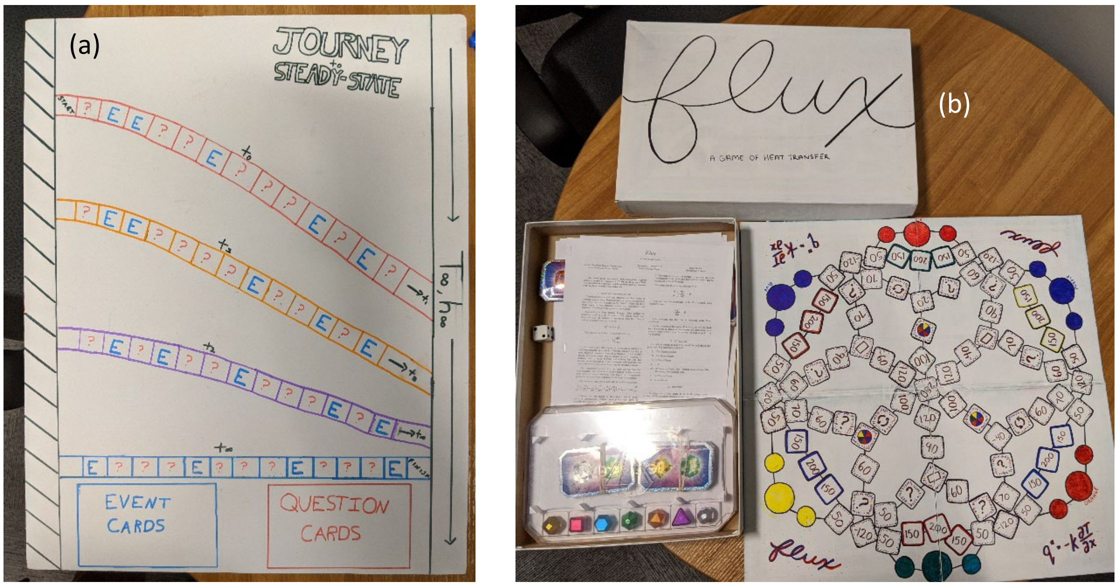

Figure 6 (a) and (b). Heat transfer board games created by groups for their project. Rules and more detailed pictures are available at sciencetheworld.com.

<u>Redistribution of the projects to future students</u>

All students were asked for permission to redistribute their projects, as part of an end-of-semester survey. Permission was necessary from all group members to be able to share the project; one group member declining any level of permitted use meant the project would not be shared.

Table 4. Permission given for distribution of course projects.

	Fall 2017	Spring 2018	Fall 2018	Spring 2019	Fall 2019
Full Permission	31	26	18	33	30
No/Limited Permission	19	4	8	2	3

After the first semester (Fall 2017) of the project, all the permitted contribution projects that were deemed by the instructor to be of an acceptable quality were provided all at the beginning of the next semester (Spring 2018) on the course's Blackboard site. Projects were sorted into folders based on the concept addressed in the project. Students were informed of their availability on the first day of class, and were encouraged throughout the semester to make use of them as desired. Beyond this means of providing the previous work, however, no further integration of the previous projects was conducted.

An end-of-semester survey was conducted of the Spring 2018 students to get feedback on the project and the learning materials created. From the survey, 33 of 36 students reported they found the project helpful in understanding the concepts addressed in their project, and all 36 students claimed that the project helped them to better communicate chemical engineering concepts. However, when asked to review how helpful the Fall 2017 semester projects were, 25 of the 36 Spring 2018 students reported having made use of the previous projects, but only 16 of 36 made use of the projects for learning purposes. Many of the students simply reviewed the previous projects for guidance in the creation of their own projects. Given that half of the class had requested additional learning material in the mid-semester evaluation, there was some disconnect between providing the projects to the students and their actually making use of them.

To some degree, the lack of student involvement with the course contribution projects should not be surprising. Educational videos, for example, have been previously noted for failing to be engaging if the viewer is simply passively watching them, but finding means to engage the viewer with the video allows for the potential to better inform and enlighten.[11,12] Thus, following the Spring 2018 semester with limited student involvement in previously developed projects, while all the previous content was provided on an accessible site, certain high quality projects were highlighted each week. As part of eight problem sets throughout the semester, an optional extra credit opportunity was provided if the students reviewed and critiqued two of several listed projects that addressed course concepts relevant to the problem set. As part of the critique, students were asked to 1) rate their enjoyment of the learning tool on a scale of 1-10, 2) critique the learning tool, 3) describe the conceptual content presented, and 4) rate their confidence in concepts presented on a scale of 1-5. These ratings were not to be directly correlated with student performance or improvement, as the ratings might vary depending on students' preferences, but would instead help students express their critique and their self-assessment by allowing for a quantified answer. The number of extra credit critiques completed each semester are presented in Figure 7.

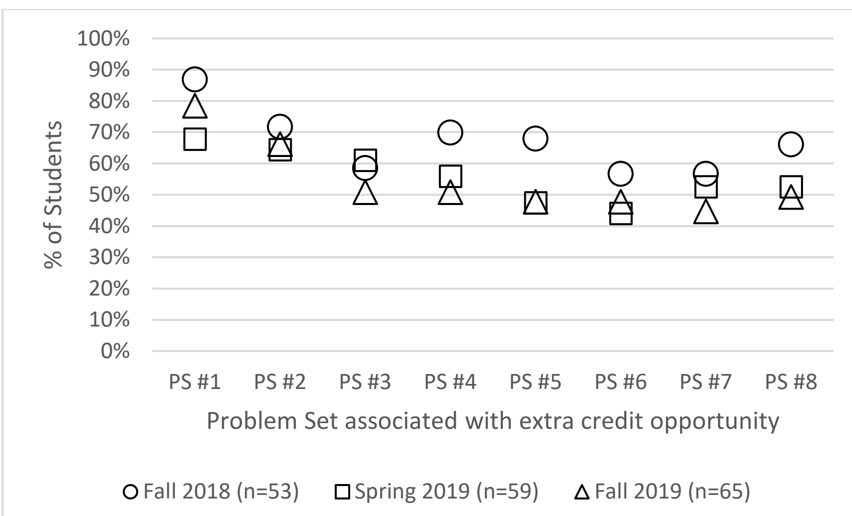

Figure 7. Percentage of each of the extra credit assignments completed each semester reviewing previous project work.

In the Fall 2018 semester, the students completed an average of 5.3 ± 0.8 of the 8 extra credit assignments. In Spring 2019, students completed an average of 4.4 ± 0.6 of the assignments, and an average of 4.4 ± 0.9 of the assignments in Fall 2019. In general, the submitted critiques were thorough, considered, and detailed, with most students writing one to two pages for each pair of critiques. Students fully described the content of each project, rated their impression of the quality of the project, and then focused specifically on the concepts presented by the project itself and how they were impacted by it. The numerical ratings given to the projects varied widely depending on a number of factors, including if the students enjoyed or disliked the art, cared for the story presented, or thought the effort put into the project was sufficient or lacking. The ratings given to their confidence varied as well, depending on whether or not the students felt they had already learned the concepts well enough, if the projects basically served to reaffirm their understanding, or if the concepts finally made sense to them. From an instructor's perspective, the scores were not the point of the critiques, but instead meant to provide a means for the students to better engage with the content provided.

Additional material beyond the previous projects suggested for critiques were all shared on the instructor's website at sciencetheworld.com.

<u>Student response</u>

Student feedback to the project has been mostly positive, as collected through an end-of-semester survey provided to students. Students were asked a series of questions on the survey, first focusing on the work they put into completing their own project, as presented in Table 5. Student answers were in the form of short paragraphs, asking them to respond either yes or no, and explain their answer. The majority of students since Fall 2018, when students began completing the critiques, responded positively that the project helped their understanding and ability of the course concepts as well as their ability to communicate chemical engineering concepts. With respect to doing the project itself, students appreciated the opportunity to work on a project that was unique from other standard course projects and allowed for them to integrate their creativity with their learning.

Table 5. Summary of positive student responses to their opinion of the project itself.

	Fall 2018 (n=51)	Spring 2019 (n=53)	Fall 2019 (n=59)
Did you find the project was helpful in terms of your understanding the concepts you addressed?	84.3%	96.2%	89.8%
Did you find the project helped you better communicate ChemE concepts?	94.0%	96.2%	98.3%

Additional comments from students on their work on the project was mostly positive. These included responses focusing on their enjoyment of the project itself, and on their perceived benefit in having completed the project:

- "Course contribution project … was fun, reinforced the concepts, and showed a very different perspective on the material and how it can be applied."
- "One of my favorite assignments I've done in college."
- "Effective."
- "I really liked the fact that we did a course project. It was a fun way to gain a better understanding of heat transfer."
- "Having to write a script that smoothly describes the thinking process involved helped."
- "The course contribution project is extremely helpful to learning course material."
- "Being forced to conceptually understand helped a lot."

Some negative comments focused on the amount of time completing the project required:

- "Would prefer a presentation to a comic or video because drawing and video editing seems like kind of a waste of time"
- "Fun to do something for a change but was a lot of work."

Students were also asked questions about their interactions with project outputs from previous semesters, again in the form of short paragraph answers explaining a yes or no answer. After creating the optional critiques, approximately 90 percent of students or more have interacted with the previous projects each semester. One survey question asked how much the students' interactions with previous projects helped to guide their own work; this number has dropped off as students have begun alternative project types like simulations or games for which there were not as many previously created works. Finally, at least 84 percent of students each semester have felt the previous projects helped with their understanding of course material.

Table 6. Summary of positive student responses to their interaction with the previous projects.

	Fall 2018 (n=51)	Spring 2019 (n=53)	Fall 2019 (n=59)
Did you review the previous projects?	96.1%	92.5%	96.6%
Were they helpful in guiding the development of your project?	91.7%	85.7%	75.9%
Were they helpful in better understanding the course material throughout the semester?	89.6%	95.9%	84.5%

Student comments were revealing. A few in particular recognized the benefit of concepts being communicated to them from a peer:

- "A lot of the comics explained concepts the same way I would, which made them easier to understand."
- "Sometimes it is easier for me to learn from another student (or someone who is not an expert) because we likely approach problems in a similar way or have the same questions."

Students recognized that the shift to a visual presentation necessitated that the concepts be connected with applications, which they found beneficial.

- "Provided real life examples of course material which made the topics easier to visualize and understand."
- "Valuable project that helps clarify concepts. Allowed us to find real applications to the concepts."

Student comments focused on the how the previous projects connected well with their learning outside the classroom, and how they could structure their learning to better help themselves:

- "Were like reviews for after I'm done with the HW.
- "I usually watched them before the HWs and it helped refresh my memory about the topic before attempting the HW."
- "Some … exposed areas of my notes that were not as thorough"

While most students were positive, some comments were negative with respect to the previous work, usually if the students wanted the projects to go further:

- "They didn't go into enough depth to supplement learning."

<u>Evaluation of Student Understanding</u>

The majority of the projects focused on heat transfer as opposed to mass transfer, primarily because of the length of time in the course spent discussing heat transfer before mass transfer was included. As such, the first two exams in the course provided some insight into whether the projects and previous work were beneficial to the students' understanding. The first exam covered general concepts of conduction and convection, shell balances, Fourier's Law, the heat equation, calculating conduction in single and composite walls for multiple coordinate systems, and conduction in fins. Box plots depicting student performance on the first exam over several semesters is presented in Figure 8. Two semesters worth of data is included before the course project was introduced in Fall 2017.

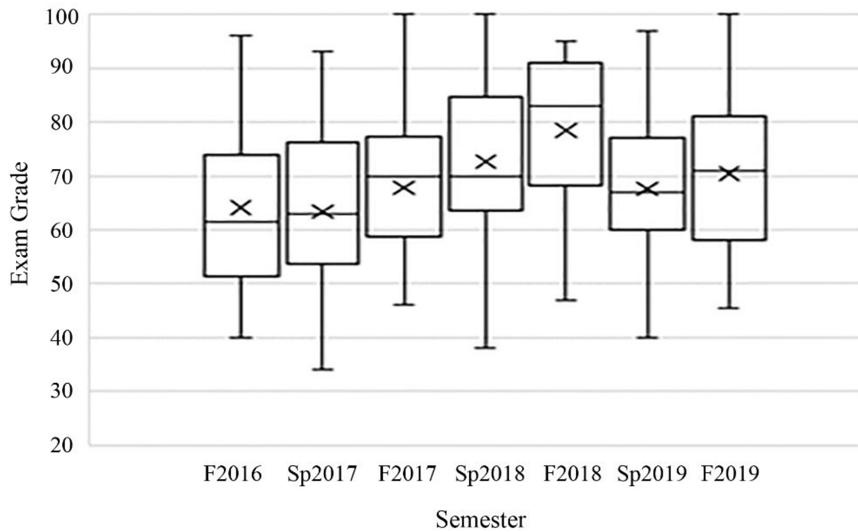

Figure 8. Box plot representation of the first exam grades over several semesters; the course project was introduced in Fall 2017, and departmental curriculum was restructured starting in Spring 2019.

There is an observable trend in the average and median exam grade over the first three semesters of the project. In Spring 2017, before the project was introduced, the exam average was a 63.4 ± 15.9, with a median of 63. Over the next three semesters, the average improved to 67.8 ± 14.1, 72.7 ± 14.3, and 78.4 ± 14.4, with the median grade improving to 70, 70, and 83. No other factors in the course were changing, and indicated that the simple development of the projects themselves were potentially beneficial to the students. A paired two tailed t-test comparing the results from Fall 2016 to Fall 2018 indicated statistical significance in the results ($p = 0.00002$). In Spring 2019, other curriculum changes in the department led to a restructuring of which semesters that the lab courses were held, and introduced a new cohort of students who were not conducting heat transfer experiments at the same time as their heat transfer course. This is the most likely explanation for the sharp drop off in student performance in Spring 2019 and Fall 2019 semesters.

The second exam covered previous topics while focusing on boundary layer theory, calculation of convection, Prandtl and Nusselt numbers, heat exchanger design and calculation, and boiling and condensation. Student performance on the second exam is presented in Figure 9, with two semesters of data before the course project was introduced again included for comparison.

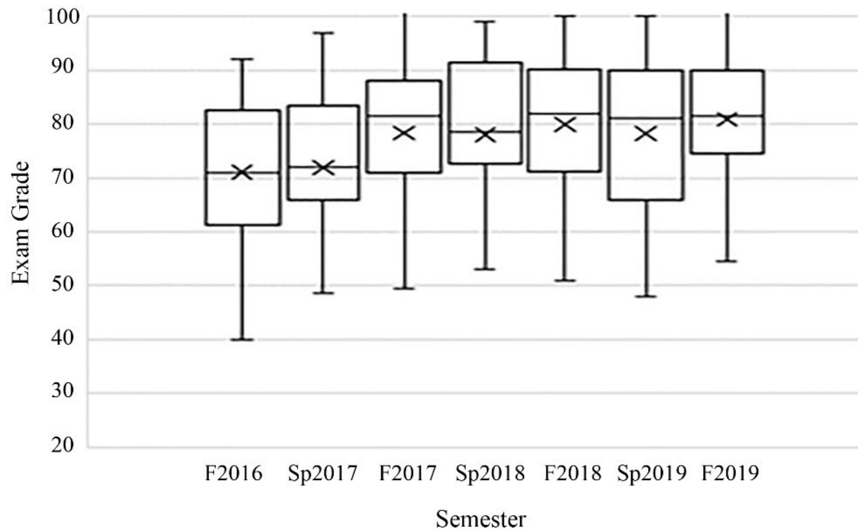

Figure 9. Box plot representation of the first exam grades over several semesters; the course project was introduced in Fall 2017.

In the two semesters before the project was introduced, the class average was 69.6 ± 15.9, with an average median of 70; in all semesters afterwards, the average was 79.1 ± 14.1 with an average median of 80.9. A paired two tailed t-test comparing the results from Fall 2016 to Fall 2018, again distinguishing between before the project to just before the lab courses changed, indicated statistical significance in the results ($p = 0.012$). Given that the exam questions changed every semester, this continued improvement strongly suggests that the course project was helping to improve students' understanding of the concepts.

Conclusion

In response to students' requests for more learning material in their courses, curriculum-producing projects were integrated into a heat and mass transfer course, with the project deliverables being shared with future iterations of the course. The course material was best integrated into the course by providing students the opportunity to critique previous work in return for a small amount of extra credit. The majority of students responded that the course project was engaging and fun, and helped them to learn. Exam performance suggested that the project was indeed supporting student understanding.

With respect to the student requests for more learning tools, which initially inspired this project, further iterations of the course continued to receive the same requests. In three semesters after the critiques were introduced, 48 percent of students requested even more material in the Fall 2018 semester, followed by 34 percent of students in Spring 2019 and 51 percent of students in Fall 2019. While the efforts have been successful in supporting students' understanding, the continued student responses suggest that there is no maximum for the amount of material that can be provided.

With respect to the projects produced, no definitive project type was determined to produce the highest quality learning materials. The final products are heavily dependent on the student teams, their creativity, and effort. In general, the comics, videos, games and simulations project types all led to examples of effective learning materials, and could potentially be utilized by other instructors for their own students. However, it is clear that there is benefit to students, both in their self-perceived and exam-assessed understanding, of having additional tools available for supplementing their learning, particularly if those tools have been created by students in previous iterations of the course.

The completed projects will continue to be available to students in future iterations of the course, with additional projects of higher quality also added to the accessible list of learning materials. While certain projects may continue to be recommended as extra credit options, all permitted projects of high quality will be made available to students digitally. It is possible that some of the projects could potentially be revisited and improved upon through direct collaboration between the students and the instructor; this has not been discussed with any of the groups but is a possibility for further consideration.

In order to determine if the outcomes of this project are reproducible, a version of this project will be introduced into Northeastern 's fluid mechanics course in an upcoming semester. In order to better analyze the student's self-reported enjoyment and improvement, a 4-point Likert scale will be used on the end-of-semester surveys to more accurately assess and quantify student responses. An ANNOVA analysis will also be utilized for better comparison between semesters.

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