

The Class and Home Problems section is intended to present novel and innovative scenarios that can enhance the teaching of chemical engineering topics. Submissions must have clear learning objectives, outcomes, or similar statements. The fit within a typical chemical engineering (or closely related) curriculum should be clear. Problems may represent a new application of fundamental principles, substantive adaptations that enable effective pedagogical approaches, or new non-proprietary applications of software. Manuscripts should follow the same general guidelines as other *CEE* submissions, but should be submitted directly to Dr. David Silverstein (david.silverstein@uky.edu).

## IDENTIFY-SOLVE-BROADCAST YOUR OWN TRANSPORT PHENOMENON: *Student-Created YouTube Videos to Foster Active Learning in Mass and Heat Transfer*

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We are all intimately familiar with a variety of mass and heat transfer concepts as an integral part of daily life. For example, brewing a cup of coffee relies heavily on principles of leaching, fluidized beds, thermodynamics, and solid-liquid equilibrium. As such, students exhibit a seemingly effortless comprehension of difficult concepts in mass and heat transfer when presented with familiar everyday examples (the “layman” approach). Unfortunately, when confronted with the deductive teaching style adopted in most engineering classrooms, proceeding from general principles to equations to practical applications (the “scientific” approach), students often fail to take full advantage of the natural learning method.<sup>[1]</sup> Therefore, even with the use of countless real-world examples, productive learning of mass and heat transfer in the classroom remains a challenge for undergraduate students, prompting the need to identify innovative methods to enhance classroom learning proficiency among college students.

One of the deficiencies of deductive teaching methods<sup>[2]</sup> is a reliance on well-defined, convergent, theoretical problem sets, which has led to inadequate critical thinking capabilities in students. Innovative active-learning strategies such as those incorporating social<sup>[3]</sup> and visual<sup>[4]</sup> digital media platforms, problem-based learning,<sup>[5]</sup> and project-based learning<sup>[6]</sup> have

been shown to maximize student learning in the STEM fields.<sup>[7]</sup> Among these strategies, YouTube videos continue to provide engaging educational values to the digital native generation.<sup>[8,9]</sup> Project-Based Learning (PBL) has gained prominence for

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cultivating global skills like creativity and analytical thinking<sup>[10]</sup> through activities featuring student choice, sustained inquiry and reflection, and collaborations between peers and instructors to identify and solve an open-ended problem with real-world relevance.<sup>[11]</sup> Given the current generation's tech-savvy tendencies, we recognized the opportunity to initiate a new active-learning method to induce more engaging and self-reliant learning attitudes by judiciously marrying the YouTube digital media and the key features of PBL.

The focus of this paper is to describe a novel active-learning method: a three-stage course project titled "Identify-Solve-Broadcast Your Own Transport Phenomenon." The three distinct stages—Identify, Solve, and Broadcast—embody the key features adapted from PBL,<sup>[11,12]</sup> and were designed to constructively shuttle the students' understanding between their qualitative layman instincts and quantitative scientific training. In addition, they uniquely and effectively merge the students' natural learning habits and their digital habits for an improved learning outcome. This practice can be adapted to other chemical engineering courses as an innovative form of class and home problems to improve student learning. Detailed below are the project implementation logistics, followed by a discussion of representative projects submitted. A brief evaluation of the impact of the project, specifically the broadcast element, on the students' class performance is also described.

## IMPLEMENTATION

Since its introduction in the Mass and Heat Transfer course (ChE342) curriculum at the University of Michigan (UM) in 2008, this course project has been shown to be a creative way for K-12 outreach.<sup>[13]</sup> Until 2013, the course project comprised only the identify and solve components (detailed below). While students expressed a general positive feeling about the course project's effect on improving their understanding of the subject, this effect was not prominent by the end of the semester.<sup>[13]</sup> To maximize the positive impact on student learning and promote active learning, a new component—broadcast—was conceived and introduced into the course project in Fall 2014. For the pilot run, the objective of the ChE342 project was to ideate and create (identify and solve) and publish (broadcast) an informative and captivating 3-5 minute YouTube video based on mass and heat transfer concepts of students' own choice.

In the identify stage scheduled around the second half of the semester, the 175 undergraduate students enrolled in the ChE342 course at UM in Fall 2014 were divided into 36 groups of 4-5 based on their own choices to improve their teamwork experience. An open-ended challenge was assigned to develop a project proposal that demonstrated their chosen mass and heat transfer topic in an informative and engaging manner. This project topic could be within or beyond the established course curriculum, and the students had the

freedom to use any course material, literature, and digital resources, giving them the opportunity to explore a broad range of topics and encouraging collaborative self-directed learning. A Google spreadsheet was created and shared with all student groups for submission of their project proposals with a first-come-first-serve policy to ensure each proposal was unique. After posting their initial proposals, each group went through a rigorous, instructor-directed proposal defense challenge to ensure the scientific correctness and complexity, as well as experimental/simulation feasibility of the project. Finalized project proposals were posted by the instructor on the course website. Overall, the identify stage strengthens the students' qualitative layman understanding and prepares them sufficiently to progress to the scientific solve stage.

In the solve stage, inspired by a method called "YouTube Fridays,"<sup>[14]</sup> students were required to (a) design an original experiment or simulation of their selected mass and heat transfer topic from the identify stage, (b) create a problem statement based on this design with the definition of necessary assumptions and variables, and (c) solve the problem statement by deriving quantitative results using the governing transport equations introduced in class. In cases where an unduly complex phenomenon was selected—such as the drinking bird example ([bit.ly/MHTvid1](http://bit.ly/MHTvid1))—and quantitative analysis or simulation was not feasible, the students were required to identify one or two key experimental parameters, predict a well-structured, rational outcome for the experiment (the engineering estimate), and validate the prediction with experimental data. At the end of the semester, each student group was required to submit a project report describing the selected topic, experimental design, problem statement, solution, and experimental data analysis. Each group was also required to perform a live in-class demonstration or simulation, accompanied by a poster to explain the underlying engineering concepts of their project to high school students, UM graduate students, and faculty. The requirements and grading rubrics for the written report and presentation, and the logistics for K-12 outreach event, are detailed elsewhere.<sup>[13]</sup>

Selected project reports, posters, and presentation snapshots with high and low scores from previous years were discussed in class to provide students necessary guidelines for completing the assignment. This also helps with quality control and uniformity in the scientific sophistication.

In the broadcast stage, the students were pushed to pursue the next level of understanding by distilling complex symbols, equations, and graphs into engaging and instructive digital media, thus encouraging them to break away from the scientific perspectives of the solve stage and return to their natural layman instincts. Each student group was required to create a 3- to 5-minute video of their demonstration/simulation to disseminate the project to not only their peers but also a broader audience over the internet via a multimedia platform like YouTube. A standardized scoring rubric was used

for assessment of the videos to enable uniform grading, and included six essential elements: (i) a daily phenomenon that inspired the experiment, (ii) the purpose and rationale of the experiment, (iii) the design and execution of the experiment, (iv) a concise explanation of the mass and/or heat transfer principle underlying the project, (v) a short summary of the demonstration, and (vi) the contribution of chemical engineers to real-world problem solving. To guide the students in the video-making process and illustrate the quality of work expected, an example video was shown in class. Groups also scheduled regular planning meetings with the course instructor and teaching assistants to organize their project demo into a cohesive video product. Filming logistics and equipment loans were supported by the Digital Media Resources at UM. Production, conversion, and editing of audio-visual digital media were supported by the GroundWorks Media Lab of the Digital Media Commons and the Computer-Assisted Engineering Networks (CAEN) at the College of Engineering at UM. All videos were submitted to the instructor via Google Drive or Dropbox and were reviewed by the instructor prior to being uploaded on the course's YouTube channel titled The Fun of Mass and Heat Transfer ([bit.ly/MHTChannel](http://bit.ly/MHTChannel)).

## STUDENT-CREATED PROJECTS AND VIDEOS

During the Fall 2014 "Identify-Solve-Broadcast Your Own Transport Phenomenon" pilot for the Mass and Heat Transfer course, 36 unique student-created projects were submitted and the videos were broadcast on the course's YouTube channel titled The Fun of Mass and Heat Transfer ([bit.ly/MHTChannel](http://bit.ly/MHTChannel)).

Provided here is a sampling of the projects that reflect the ability of the three-stage course project to constructively transition the students' understanding of mass and heat transfer principles from a qualitative perspective (identify) to a quantitative perspective (solve), and finally back to their qualitative layman instincts (broadcast), as outlined in Figures 1-2. Here we highlight two unique categories that improve student learning in mass and heat transfer, but more importantly, equip them with vital career skills such as creative thinking, self-motivation, critical judgement, and self-direction to succeed in a competitive global economy.

### Example 1: Musical approach to molecular diffusion

Molecular diffusion in gases can be modeled using advanced kinetic theories for molecular motion, but transport characteristics in solids and liquids are not as rigorously defined. The latter require consideration of additional complex parameters such as viscosity, porosity, ionic species, and surface area.

Various student groups designed informative projects to explore the effect of some of these parameters on mass diffusivity at various interfaces, such as the effect of temperature ([bit.ly/MHTvid2](http://bit.ly/MHTvid2)) and viscosity ([bit.ly/MHTvid3](http://bit.ly/MHTvid3))

at a liquid-liquid interface and different media at a porous solid-liquid interface ([bit.ly/MHTvid4](http://bit.ly/MHTvid4), [bit.ly/MHTvid5](http://bit.ly/MHTvid5)). One project stood out from the rest for its unique entertainment value ([bit.ly/MHTvid6](http://bit.ly/MHTvid6)). The students took their visually captivating project on the varying diffusivity in different media at a liquid-liquid/semisolid interface (Figure 1) to the next level by producing a rap musical inspired by the opening theme of the popular sitcom "The Fresh Prince of Bel-Air." The familiar rhythm combined with witty lyrics led to the creation of a uniquely engaging video titled "Fresh Prince of Mass Transfer," which concisely recounted the project experimental design, scientific analysis, and observed results in an immensely entertaining manner. The captivating nature of this video perfectly highlights the students' ability to distill complex concepts into simplified explanations for fun and engaging visual material, which piques the viewer's curiosity to further explore these scientific topics.

This video epitomizes education in the 21st century, which is largely dominated by "edutainment" (*i.e.*, education in entertainment) because of the transformative influence of digital education platforms like Khan Academy and YouTube: Education that makes learning fun and interactive.<sup>[15]</sup> The engaging creativity exhibited in the video exemplifies the students' enthusiasm and commitment, and embodies successful student motivation by the three-stage active-learning method.<sup>[4]</sup>

### Example 2: Transcending the boundaries of the curriculum

The curriculum for the Mass and Heat Transfer course at UM provides structure and organization, but at the cost of limiting the scope of the subject due to restrictions in time and student workload. The freedom to choose their own topic in the identify stage provides students the valuable opportunity to explore interesting new topics beyond the scope of the curriculum. The 2014 Mass and Heat Transfer curriculum at UM focused on approaching mass transfer and heat transfer as independent phenomena or in scenarios where decoupling the two was a reasonable assumption. One group of students took the opportunity to evaluate simultaneous mass and heat transfer by investigating water evaporation by flowing air produced by a blow dryer as shown in Figure 2, which is a very complex problem that requires concurrent analysis of both processes involved. Using the governing laws learned in class, the students derived a rigorous mathematical model for the heat flux for simultaneous mass and heat convection and estimated the time required for evaporation of water. Incredibly, the average experimental time for evaporation matched very well the estimated time from their model within an acceptable experimental error of 10%. This project is unlike most others where the solve stage yielded semi-quantitative results at best. In the broadcast stage, the students excelled at simplifying their complex scientific project into an easily explainable form, which displayed their thorough understanding of the

**Project Title:** Diffusivity of Food Coloring through Different Media

by Benjamin Griessmann, Erica Hastings, Scott Johnston, Andrew Olson, Matthew Riley

**Video link:** [bit.ly/MHTvid6](http://bit.ly/MHTvid6)

**IDENTIFY:**

Different materials have different diffusivity.

Visualize and rap about the different diffusion rate of food dye in different materials.

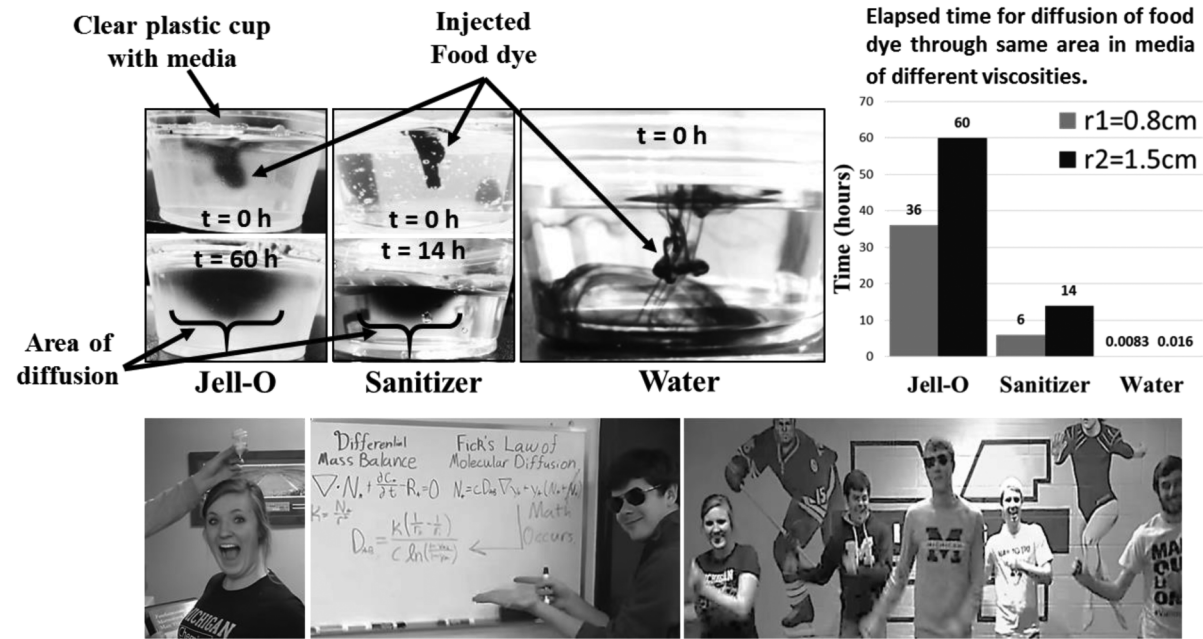
**SOLVE:**

To visualize diffusion in different materials, the group set up an experiment where they slowly and carefully injected blue food dye in three different media, namely water, sanitizer and Jell-O and recorded the time taken for the dye to diffuse through a radius of 0.8cm and 1.5cm. The following equation was used to solve for the uni-molecular spatial diffusion flux of the dye in different media.

$$N_A = D_{AB} C \nabla y + y_a N_A, \text{ where } D_{AB} = \frac{k \left( \frac{1}{r_2} - \frac{1}{r_1} \right)}{c \ln \left( \frac{1-y_{a2}}{1-y_{a1}} \right)} \text{ --- (1)}$$

Using this equation, the student simulated the diffusion flux as a function of the radius of diffusion of the dye in the three different media. As a number of complex calculations ( $k$ ,  $c$ ) and measurements (such as the local concentration of the dye in the medium,  $y_a$ ) were required for determination of the absolute diffusivity in the three media, the students instead performed a relative analysis to show the general trend in spatial diffusion flux by selecting arbitrary values for  $D_{AB}$ . Jell-O was assigned the lowest diffusivity as it has the highest viscosity and this was used to estimate the relative diffusivity of sanitizer and water. The relative variation in the spatial flux showed that the rate of diffusion was the lowest in Jell-O, followed by sanitizer and finally water. The simulation results verified their experimental results that showed the time required for diffusion to a fixed radius was the longest for Jell-O and least for water.

**BROADCAST SNAPSHOTS:**



**Figure 1.** Student-created project to visually demonstrate the effect of viscosity on mass diffusivity through different media.

topic. The systematic and meticulous design of the project strengthened the students' capacity for self-directed learning, thus highlighting the benefit of this active-learning method in imparting students with vital skills to become successful chemical engineers.

## EVALUATION

The project examples described above qualitatively showed the positive impact of the three-stage method on improving student learning. To quantitatively assess its impact, especially the broadcast component, we performed statistical comparison

**Project Title:** The Last Tangle: Can Mass and Heat Transfer Work Together?

by Chayce Griffith, Alex Pierce, Chris Rockwell, Desikan Jagannathan

**Video link:** [bit.ly/MHTvid8](http://bit.ly/MHTvid8)

### IDENTIFY:

Combined mass and heat transfer increases overall heat flux.

Calculate and measure water evaporation: compare hot blowing air, ambient blowing air and hot still air.

### SOLVE:

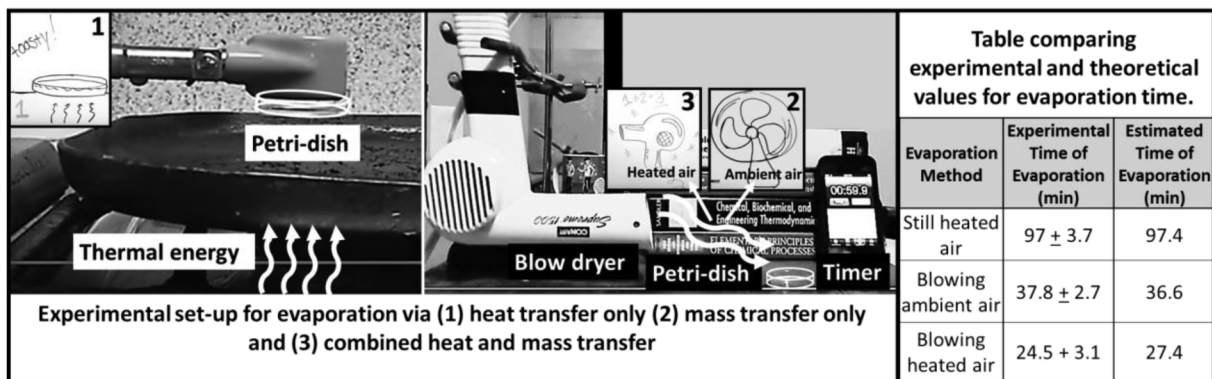
Using time as the key parameter, three different methods of evaporation were evaluated. For each set of experiments, ~1mL of water in a clear petri dish was subjected to either heat convection (333K), a cooling 'fan' at ambient temperature (mass convection) or blow drying at 333K (combined convective heat and mass transfer) until all the water evaporated. Using Newton's law of cooling and the convective mass flux equations introduced in class, the students derived a consolidated equation for simultaneous mass and heat convection described by equation 1 below.

$$\frac{q}{A} = h(T_1 - T_2) + N_A M_A (H_2 - H_1) \text{--- (2)}$$

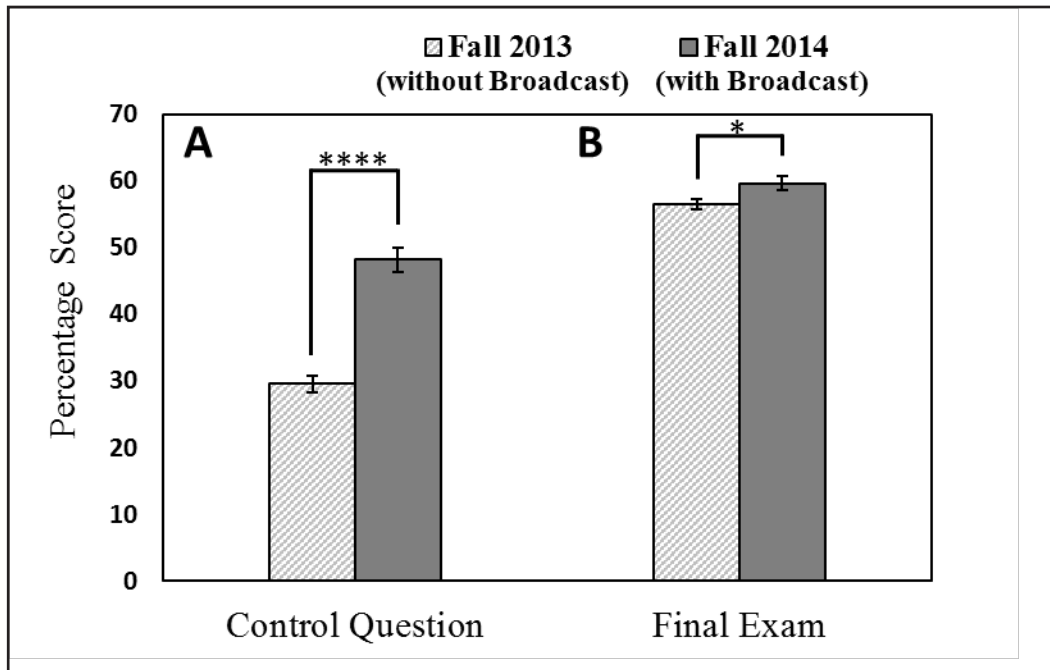
$$q = \frac{Q}{t} \text{--- (3)}$$

To quantitatively determine the time of drying in each case, the students performed extensive and complex calculations where they (i) estimated the overall heat flux using part or all of equation 1 and (ii) used this heat flux value with correspondingly calculated values for total heat transferred (Q) using equation 2. To solve for these, the students had to perform a rigorous analysis of the problem conditions and estimate a number of parameters to determine the various heat/mass transfer coefficients (h, k), such as the Sherwood number, Reynolds number, Nusselt number, heat enthalpy (H), etc. The rigorous scientific analysis of each case yielded quantitative results that were validated by the experimental observations within a 10% error range, as shown in the table below.

### BROADCAST SNAPSHOTS:



**Figure 2.** Student-created project to demonstrate the combined effect of mass and heat transfer using a blow dryer for water evaporation (some elements have been dramatized for image clarity).



**Figure 3.** Comparison of student performance on (A) the control problem and (B) final exam between Fall 2013 ( $n=156$ ) and Fall 2014 ( $n=163$ ). The error bars represent the standard error in the mean (SEM) for each group. Two-tailed Student's  $t$ -test yielded  $p < 0.0001$  (\*\*\*\*) for the control problem scores and  $p < 0.05$  (\*) for the final exam scores.

of student performances in the end-of-term final exam from Fall 2013 (without broadcast) and Fall 2014 (with broadcast) on two levels. Firstly, a challenging control problem centered on mass transfer across a dynamically changing interface was included in both exams, but in two different forms. These two versions were specifically designed to be very similar in terms of both concepts and complexity. To eliminate biases due to external circumstances, only the scores of students who passed the course were included in our analyses. As shown in Figure 3A, the students performed significantly better on the control problem in Fall 2014 ( $n=163$ ) than in Fall 2013 ( $n=156$ ) (two-tailed Student's  $t$ -test,  $p < 0.0001$ ). This improvement was even more remarkable because unlike in Fall 2013, the final exam in Fall 2014 did not include any guiding questions designed to help the students solve the complex control problem.

Secondly, the total final exam scores between the two years were compared to assess the effect of the broadcast component on students' overall performance in this course. As shown in Figure 3B, the statistically significant increase (two-tailed Student's  $t$ -test,  $p < 0.05$ ) of the average final score from 56.5 (SEM=0.73) in Fall 2013 to 59.6 (SEM=1.01) in Fall 2014 clearly demonstrates a positive impact. Taken together, these data suggest that the broadcast component of the described three-stage course project played a critical role in improving student learning of mass and heat transfer. This could be partially attributed to its alignment with the students' digital

savvy tendencies, as exemplified by their high enthusiasm in watching each other's videos, versus the minimal likelihood of reading each other's report. Thus the employment of a multimedia platform also incorporates the power of peer effect, which is known to be effective in engaging students and improving their learning outcome.<sup>[16]</sup>

### SUMMARY

Reported here is an innovative form of a class and home problem: "Identify-Solve-Broadcast Your Own Transport Phenomenon" integrated in a Mass and Heat Transfer course to implement the active-

learning strategy that uses modern technology to shuttle students' understanding of complex principles between qualitative and quantitative perspectives. The "layman" approach in the identify stage, which mirrors the qualitative nature of in-class problems like i>Clicker questions, encouraged students to select their own transport topic to motivate self-directed learning and reinforce course material. The solve component, which can supplement traditional convergent homework problems sets, honed the students' ability to critically analyze, model, and solve challenging open-ended problems on complex transport phenomena. Finally, the broadcast stage, a critical element of the pilot in Fall 2014, integrated students' digital habits in the classroom, boosted their confidence, and promoted peer-to-peer learning.

Overall, this three-stage course project described here is an effective type of class and home problem that encourages student-centric learning while enhancing self-motivation, creative thinking, and critical analysis. Future implementations of this 21st century PBL-inspired pedagogy will be focused on encouraging students to design projects with more rigorous quantitative analyses. The course YouTube channel, The Fun of Mass and Heat Transfer, will also be used as an outreach platform to engage more K-12 students and reach a broader audience. Indeed, the analytics of the course's YouTube channel have recorded a global viewer demographic, with viewers from the United States, Australia, Japan, Russia, India, France, and many more geographic locations.

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