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Evaluation of evidence-based teaching techniques in a graduate fluid dynamics course

Dr. John Palmore Jr, Virginia Tech

John Palmore Jr is an Assistant Professor in the Mechanical Engineering Department at Virginia Tech. He specializes in multiphase thermo-fluid flows. Dr. Palmore's technical research focuses on developing numerical algorithms for simulating these flows using high performance computing. His educational research focuses upon incorporating technology into the classroom. Dr. Palmore is an active member of several professional societies including the American Institute of Aeronautics and Astronautics, the American Society of Mechanical Engineers, the Society for Industrial and Applied Mathematics, and the National Society of Black Engineers.

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Abstract
This paper explores the use of modern, evidence-based teaching techniques in a graduate fluid dynamics course. Evidence-based learning and teaching techniques have become increasingly popular in undergraduate engineering courses, however, there is less documentation of the efficacy of the techniques in the graduate context. The study focuses on the use of three techniques that integrate well with the author's focus on the use of computer technology in the classroom. The techniques are guided notes, peer discussions (using Piazza), and gamification (using *Kahoot!*). The efficacy of the techniques in increasing student engagement with the course material and student understanding is self-assessed through a survey administered to the students at the end of the Fall 2019 semester. This assessment method is limited due to the small sample size studied (nine students), however, the data suggests that the use of these strategies may be helpful in student education. From the assessment, it was found that guided notes were considered helpful by students, and they were particularly helpful for studying. Online discussion using Piazza was not appreciated, however, the incorporation of discussion into the gamification framework of *Kahoot!* was appreciated.

Motivation
This work was motivated by the current trend in STEM education towards use of evidence-based practices (EBP) for teaching. In this context, EBP refer to teaching strategies that have been used and evaluated in the classroom in systematic manners. The use of these strategies has grown significantly in engineering courses, and is particularly used in introductory courses. However, there has been much less understanding of the use of these strategies in higher level courses. The current work implements and tests a suite of complimentary EBP in a graduate-level fluid dynamics course.

Dunlosky et al. [8] reviews several EBP for classrooms. They discuss the efficacy of each strategy, the quantity of research supporting each strategy, and the practicality of implementing each strategy. They conclude that the most effective strategy to increase student performance is administration of practice tests, and this is supported by other analysis [1]. Notwithstanding the importance of practice exams for student learning, this study will focus on strategies that exploit computer technology and the internet. Due to the common trend of adoption of computer technology, this seems like an interesting arena to explore. Accordingly, the current work chose to focus on three strategies that have been gaining in popularity in the modern engineering classrooms: guided notes, peer discussion, and gamification. The effectiveness of the techniques in student learning was self-assessed by the students through a survey administered at the end of the course. These results are limited by the standard difficulties surrounding the reliability of self-assessment [7] as well as the small sample size typical of elective graduate courses (nine students).

Guided Notes

The guided notes technique provides students with a incomplete copy of the lecture before class. The students are then able to follow the lecture and fill-in the notes as the class progresses. The technique is also variously called skeletal notes and skeleton notes. Guided notes have been demonstrated to be an effective tool at enhancing student learning, and they may be particularly valuable to students with disabilities [11]. Gonzalez[10] reviews note taking as a practice and lists several properties of good notes. Interestingly, guided notes can be used in a way to satisfy almost all of these criteria.

Guided notes are effectively a technique for teaching students on how to take notes for the course. It is known that note taking improves student performance, but it is also known that students take incomplete notes [13]. However, it has been shown that when students are instructed on how to form notes in the class, their notes better capture the key course information [23]. Even without formal instruction in note taking, when students are given appropriate cues for the importance of information, quality of note taking and achievement improves [14].

Guided notes may also help students better synthesize information in the class. Another common limitation of student note taking is that students tend to take notes in a rote manner rather than processing the information [13]. However, this may be a natural part of the note taking process as it is difficult to both record notes and synthesize information simultaneously [13]. However, by removing some of the mechanical aspect of note taking, students are more free to think about course concepts, synthesize information, and make questions and comments in class [11].

Guided notes are also a natural framework to incorporate visuals into notetaking [10]. It has been demonstrated that students are better able to learn and recall information when it is presented in a more visual form [27]. This strategy has been effectively applied to instruction in engineering courses [22].

For this course, the Guided Notes technique is deployed using a computer technology focused strategy. This author typed the guided notes using LaTeXand distributed a PDF document online before class. In class, he used his tablet to project the guides onto a screen. As the lecture progresses, he used the stylus to write on the tablet and fill in the guides. Students were similarly able to fill in the guides either using printed copies on paper or using their own tablets and laptops. The strategy is well suited to either in person or online lecturing.

Results

The first question to be asked is the usefulness of guided notes for taking notes in class. 8/9 of the students used the notes for following lecture, and 1/9 students chose to make notes on their own. Of these eight students, seven felt that the guided notes definitely or probably aided their understanding of course materials. Interestingly, *all nine students* used the guided notes to help them do homework and study for exams. This demonstrates a potential advantage of the guided notes technique over other lecturing strategies, because it is known that providing instructor notes increases student performance [14]. Therefore, even students that do not use the guides for following lecture, still benefit from the structure that they provide for studying. One student remarked,

> . . . I make my own notes based off of what [the instructors] write and say and other students say during the lecture. That being said, I do appreciate the effort that goes in to preparing guided notes and they are handy as reference.

This statement strongly echos the result of [11] in that students are able to focus more on synthesis instead of mechanical transcription. However, it applies even to the situation where the student does not directly use the guided notes. Because the guided notes are available at the convenience of the student, the student exploits this to focus on synthesis of course concepts rather than on transcription during lecture.

Note that while there was a general appreciation of the guided notes among students, there was also a concern among students that it made note taking too easy. Particularly, students feared that the notes allowed students to follow lecture without understanding the information. This may be compared to research on the educational benefits of highlighting and underlining material from texts [8]. This review notes that students who actively highlighted material tend to perform better than those who passively engaged with pre-highlighted texts. The later concept of passively engaging with pre-formatted texts is more similar to guided notes, which explicitly emphasize certain materials by including them in the guides. This suggests that there is still research to be performed with respect to what are the best methods of formulating the notes for the students.

Gamification

Gamification is the concept of having educational games be a part of the classroom environment. These games are often implemented as simple multiple choice quizzes are polls. In practice, the implementation of gamification in engineering courses is strongly inspired by the literature of peer instruction [4, 9, 17, 25, 26], although there are some differences between these concepts. In this course, in class quizzes were given through *Kahoot!* the educational gaming platform (www.kahoot.com). This platform was chosen due to its use in several previous studies in science and engineering education [6, 16, 21, 24]. *Kahoot!* is an online gaming environment that focuses on asking multiple choice question in an engaging environment. The software uses vibrant colors and engaging sounds to help create a fun atmosphere in the class room. *Kahoot!* has dedicated apps for iOS and Android, so that student can easily access the software. Critically, *Kahoot!* is free for the students to download and use. The platform follows a freemium model so that basic features are free to use, however, the instructor may choose to purchase optional advanced features. This paper is concerned only with the basic, free features of *Kahoot!*. An example *Kahoot!* is demonstrated in fig. 1. The left image demonstrates the *Kahoot!* which the instructor must display using a projector for the class to see. The right image demonstrates the view of a student using the *Kahoot!* app on their phone. The instructor writes a prompt for the students to respond to, in this case “Please choose A”. On their device, the student then select among four choices which are identified by both a shape and color. The instructor may freely edit the text responses that students choose from, however in practice this author uses ABCD for reasons to be discussed later. As the question is displayed a countdown clock demonstrates the time remaining in the exercise, here 43 seconds. The instructor may set the clock to count down from a few

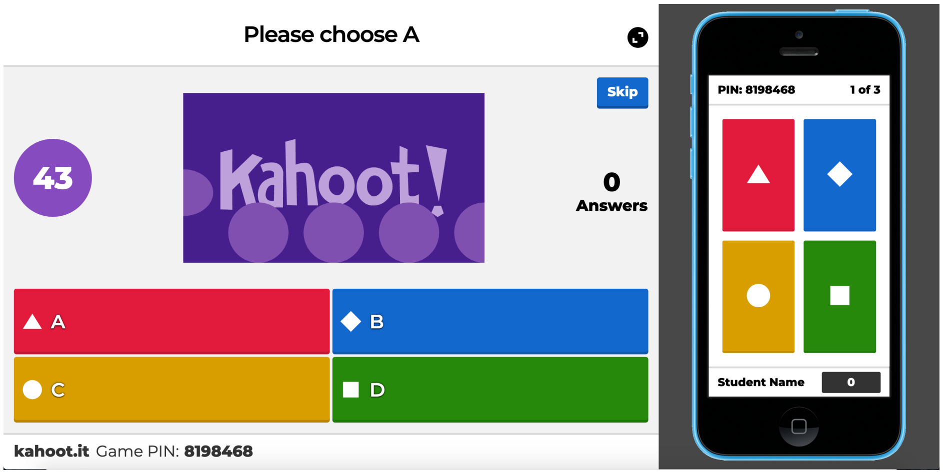

Figure 1: The basic *Kahoot!* interface.

pre-programmed options; this author typically use 20 or 60 seconds. As the clock is counting down, music is played in the background, and the music typically becomes more serious as the *Kahoot!* exercise nears its close. The number of responses to the question, in this case 0, is updated on the screen as students respond. The instructor may ask any number of questions, and students are awarded points based upon the accuracy of their responses and the speed with which they respond. In practice, this author does not use those scores for anything, however, students can be strongly motivated by the desire to win the competition. The presence of these engaging classroom phenomena is what differentiates *Kahoot!* as a gaming platform compared to a simple multiple choice quiz.

The literature has generally demonstrated positive effects of *Kahoot!* in undergraduate courses [6, 16, 21, 24]. Cutri et al. [6] used *Kahoot!* as an alternative to clickers for in-class feedback in introductory Physics and Chemistry courses. They note as a motivation the fact that *Kahoot!* is free while clickers averaged about $ 50 at the time of their study. They also note that most student thought the *Kahoot!* made the class more fun, and helped improve learning in the course [6]. Plump and LaRosa [21] review the educational theory, and make specific claims about mechanisms by which *Kahoot!* can improve student performance. The conclude[21],

- The use of vibrant colors and music potentially help students stay attentive through the exercise.
- The presence of competition encourages engagement.
- Real-time feedback allows the instructor to provide clarification in class, as appropriate.

Licorish et al. [16] further investigate the mechanisms by which *Kahoot!* work. They suggest that an important aspect of the *Kahoot!* is simply the fact that it changes the flow of the class by forcing the instructor to have a break in the lecture. Further, the *Kahoot!* tends to encourage discussion among the students. Seralidou et al. [24] compared a few types of *Kahoot!* quizzes, and came to the conclusion that students prefer the traditional multiple choice format to the "jumble" quizzes. However due to the small sample sizes used in all of these studies, the results may be considered suggestive but not definitive, and more study should be performed.

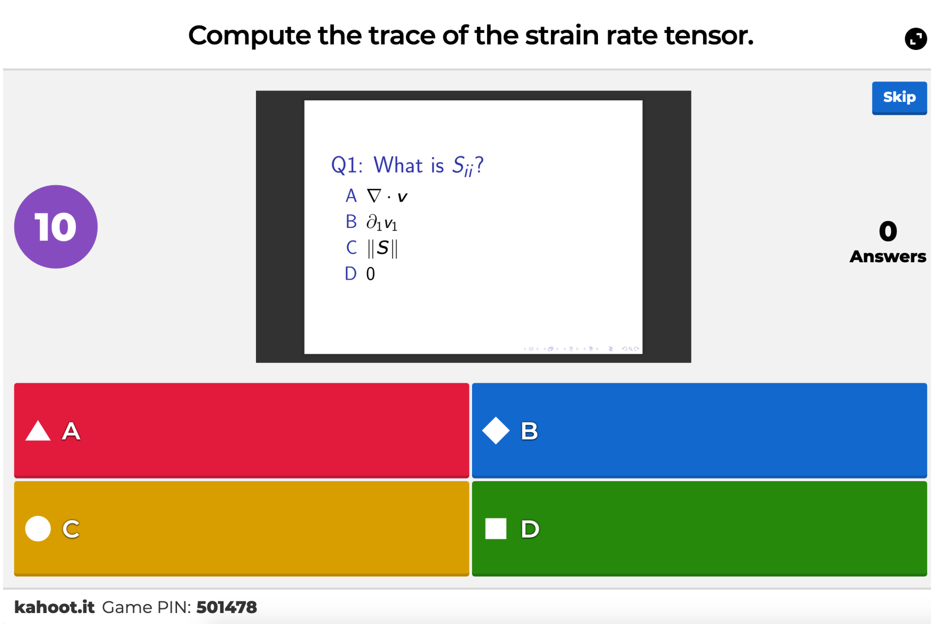

Figure 2: An example *Kahoot!* question from the course.

Unfortunately, the use of the *Kahoot!* platform strongly limits the types of questions that can be directly asked on the platform. The platform does not have a good interface for the display of drawings or mathematical formulae, which are important in upper-division engineering courses. To work around this, this author began to exploit the image upload feature of *Kahoot!* to upload a single image containing all drawings, necessary formula, and the multiple choice answer selections [20]. The students then simply choose the shape/color corresponding to ABCD in the *Kahoot!* app. An example of such an image is demonstrated in fig. 2. It can be seen that the generic purple *kahoot!* background that was demonstrated in fig. 1 has been replaced by an image containing the question. This example deals with the strain rate tensor, $\boldsymbol{S}$, that had been recently introduced in the course. Students are asked to re-express the given quantity and are given choices that demonstrate vector notation, indicial tensor notation, and norm notation. Therefore the example tests not only the students' knowledge of the definition of $\boldsymbol{S}$, but also their comfortability with the various types of mathematical notations that are used within the course.

Results

Even with this strategy, use of *Kahoot!* is still limiting pedagogically because only multiple choice questions can be used. The use of such short problems fails to appropriately test student understanding. To work around this, this author developed the following strategy [20]. Students are given a more challenging problem, such as one that may be on a homework assignment. The students are then given 5-10 to work on the example, alone. Subsequently, the students discuss their work in small groups for an additional 5-10 minutes. Then students are given a series multiple choice questions through *Kahoot!* which are related to the solution of the more complex problem. In the original study [20], students were not allowed to discuss in groups, and instead worked on each problem alone. From that work, this author learned that students genuinely appreciated the additional depth that this form of exercise allowed them to explore compared to simple *Kahoot!* exercise. This effect was only enhanced in the current study when students were allowed to discuss in groups before doing the multiple choice questions. 6/9 students found the group *Kahoot!* exercises helped them better learn the course material, and 2/9 noted no effect. Only 1/9 student preferred to work on these exercises alone instead of in a group. One student specifically remarked that working in groups allowed the student to hear explanations of the material from varying student perspectives. This process helped the student to learn more effectively. That result is not surprising, and is consistent with Mazur's original motivation for the related strategy of peer instruction [18].

Peer Discussion with Piazza

For this paper, define peer discussion to be any discussions that students have with each other about course materials inside or outside of the course. The concepts fits into the paradigm of cooperative and collaborative learning. Here students work together to learn information rather than relying solely on the instructor [2, 15]. Although the strategy pre-dates the widespread deployment of the internet [2, 15], there has been a substantial increase in the use of the strategy in the context of internet enabled computers [3, 5, 19]. Recently *Piazza* (https://piazza.com/) has become a popular tool for these collaboration. *Piazza* combines elements of the question & answer forum, the wiki, and the learning management system into one interface. It has proven successful as a tool for collaboration in computer and information science course [3, 12]. John [12] concluded that micro-collaboration on *Piazza* helped information science students acquire new knowledge, active relevant cognitive processes, and develop field-appropriate social skills.

For this class, this author encouraged students to use *Piazza* to ask any questions that they had for homework. However, in the end this author found extremely low participation. The *Piazza* platform was used sparingly for the first homework assignment. It was never used again. There are a number of possible reasons for this.

1. The use of mathematical formulae on *Piazza* is challenging unless the student is well versed in $\LaTeX$.
2. Incorporation of figures in *Piazza* is challenging.
3. *Piazza* was only used for discussion. It may need to be more fully integrated into the class experience to encourage participation.
4. The class size was small. This effectively de-anonymizes any post on the forum, and can lead to students that are embarrassed to engage with the forum.

The review [15] notes that for collaborative learning to occur students need to need to have a perception of interdependence, and it could be that this quality was in the authors use of *Piazza*. Future work will seek to better understand how to use environments like *Piazza* in the course.

Conclusion

A number of evidence-based teaching strategies were employed in a graduate course on fluid dynamics. The efficacy of the techniques was self-assessed by the nine students in the course. In addition to the standard limitation of self-assessment [7], it is important to note the limited sample size in the course. Therefore, this work should be considered as an exploratory study rather than as a general result. The work focused on three strategies that are particularly well adapted to integration with computer-based technologies. From the assessment it was determined that guided notes were used by the students and found to be helpful. This is consistent with previous literature for undergraduates and high schoolers. However, a potentially surprising result is that even the student who did not use the guided notes in lecture, did use them to study for exams. This demonstrates a potential secondary advantage of guided notes for classroom use. Gamification was studied using *Kahoot!*, and it was determined that such exercises increased the student engagement with material and ultimately encouraged learning. This is consistent with previous literature for undergraduates. Finally, the course attempted to encourage out of class peer discussion using the online forum *Piazza*, however, students chose to not participate in the forum. Future work will look towards optimizing the content in Guided Notes and *Kahoot!* exercises, and will seek to develop better mechanisms for out of class peer discussion.

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