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How To Think About Fluids In and Out of Classrooms: Developing Interactive Strategies for Learning Fluid Mechanics Online

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How To Think About Fluids In and Out of Classrooms: Developing Interactive Strategies for Learning Fluid Mechanics in a Hybrid Setting

In this paper we report on the development of strategies used in an introductory fluid mechanics course that transitioned from a fully in-person mode of delivery to a hybrid setting. We describe two sets of instructional changes we used to support students' learning in the hybrid context: first, Matlab live script documents and second, "scavenger hunt" missions of finding, demonstrating, or building fluid mechanical systems in everyday life. We employ two different instruments to track students' experiences in this course. First, we compare students' performance in a fluid mechanics concept inventory assessment that they take at the end of each semester. In addition, we also adopt a set of items from the Motivated Strategies for Learning Questionnaire (MSLQ) to measure the impacts of these changes on students' motivations and attitudes. We reflect on the implications of this transition process and provide an outline of the future developments of this work.

1. Introduction

Teaching and learning in online or hybrid settings play an ever increasing role in science, technology, engineering and mathematics education. Developing learning experiences that leverage continually evolving tools and platforms in a way that is informed by the research and scholarship on best practices and evidence-based recommendations allow educators to more effectively support students' successful achievement of learning goals and outcomes. Over the years in various ways computational methods and resources have been used to support teaching and learning in engineering courses [1, 2] including introductory courses in fluid mechanics [3, 4]. Furthermore, the significant migration of the students' learning experiences to virtual environments, which has been triggered under the mandatory responses to the onset of COVID-19 pandemic, has renewed concerns about students' success and motivation in engineering education [5]. Recent studies suggest that in the wake of such disruptions students' academic performance from 2019 to 2020 has suffered a decline (even when controlling for specific demographic groups), however pedagogical strategies play a critical factor in mitigating the effects [6].

In this paper we report on the strategies used in an introductory fluid mechanics course that transitioned from a fully in-person mode of delivery in Fall 2019 to a hybrid mode in Fall 2020. The 2019 in-person version of the course consisted of three weekly lectures and a single weekly discussion session for the entire class. In 2020, the course was delivered in a hybrid mode with all lecture sessions held online and smaller weekly discussion sections offered either online or in person, at the student option. The main course instructor delivered the discussion sections as well as the lectures in both years. In Fall 2020 we leveraged Matlab live scripts in the homework assignments to integrate the mathematical and graphical representations of the fluid mechanics problems together. Furthermore, to address the challenges that students face in terms of motivation and engagement in an online mode of delivery we developed team-based "scavenger hunt" missions around everyday fluid mechanical concepts and systems that students typically encounter in their daily lives.

In the following sections we first give an account of the instructional strategies developed in Fall 2020 and the way we sought to support students' learning experiences. Then we present the data collected in both Fall 2019 and 2020 as a basis for describing the impact of these instructions. We then close the paper by reflecting on some of the possible implications of this transition process and the ways in which we intend to continuously improve the strategies adopted so far.

2. Design of Activities: Transitioning to the Online Setting

The in-person fluid mechanics course that was offered in the Fall 2019 was based on the textbook written by the instructor of the course [7] and the lecture sessions followed a *case study* format to help concretize the subject matter and make it relatable for engineering students. For example, to teach the concepts and principles of hydrostatics, several lectures were devoted to water towers, aqueducts and canal locks. Through the examination of such engineering systems and functionalities which are developed on the basis of fluid mechanical ideas and models, we can help students develop a sense of how ideas and theoretical concepts tie to practical problems and specific engineering challenges. Case studies can also provide students with a survey of fluid mechanical systems across disciplinary lines (see Table 1).

A typical case study usually takes more than one lecture session, but each session is rendered interactive for students by posing a number of short questions that students work on individually during the lecture. This approach was used in both Fall 2019 and Fall 2020 because it allowed us to create opportunities for instructor-student interactions and in-class problem solving, whether in-person or synchronously online. Students who were not able to attend the online lectures of Fall 2020 synchronously were able to view recordings of the lecture.

Table 1. Case study topics

	Case study	**Subject matter**
1	Water towers and aqueducts	Hydrostatics
2	Siphons, toilets, and Pythagoras' cup	Hydrostatics
3	Scuba diving	Buoyancy forces
4	Fun with straws	Hydrostatics
5	Kugel ball and hydraulic jack	Hydrostatics
6	Falkirk wheel	Archimedes' principle
7	Free Jets and fountains	Bernoulli equation
8	Mercury zenith telescope	Streamlines
9	Aeroperu disaster	Pitot-static tube and airplane sensors
10	River surfing	Hydraulic jumps
11	Water-jet ball toy	Control volume analysis
12	Jet Skiing	Control volume analysis
13	Quadcopters	Control volume analysis
14	Why curveballs curve?	Irrotational flow
15	Fletter rotor sails	Irrotational flow around cylinders

16	Trinity experiment	Dimensional analysis
17	Why are golf balls dimpled?	Aerodynamics drag reduction
18	Tacoma Narrow Bridge	Wind-induced vibration and failure
19	Air bearings	Flow between flat plates
20	Capillary networks	Lumped parameter model of fluid network
21	Pregnancy test	Surface tension-driven flow

2.1. Matlab Live Scripts:

In Fall 2020 we added a new component to the weekly homework assignments. To support students' development of visual as well as mathematical intuitions for topics such as vector fields, surface integrals, and streamlines the instructor developed Matlab live scripts to accompany some of the weekly homeworks. A typical Livescript document includes a code that produces a dynamically adjustable figure either (a) of symbolically defined functions that students can input, such as the components of a velocity field or the volumetric pressure function as shown in Figure 1, or (b) of a mathematical model of an engineering system such as the rocket nozzle shown in Figure 2. With these activities students had to attend to the significance of mathematical derivations and models and to consider how changes in the behavior of a system (of equations) is explainable.

Quiver Plot of a Vector Field

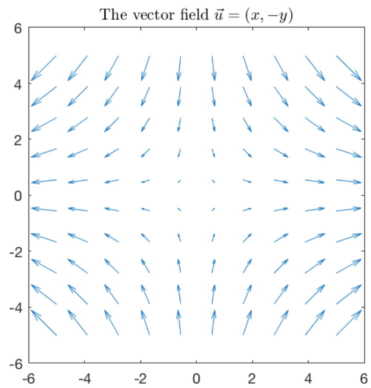
A quiver plot of a vector field places arrows (usually on a regular grid) to illustrate the (usually) 2D structure of the field. It is routinely used in fluid mechanics.

Plot your own vector field

Type in the u- and y-components of the vector field in the box below, written as functions of x and y. Note: the graph will fail if you define a function that is not defined on the doman -5<x<5, -5<y<5.

x-component of vector field [x]   # of arrows in each direction [10]

y-component of vector field [-y]   [Plot vector ε]



Plot the gradient of your own scalar field

Type in the scalar field in the box below, written as functions of x and y, and the graph will plot the gradient of that field. Note: the graph will fail or plot weirdly if you define a function that is not differentiable or well-defined on the domain -5<x<5, -5<y<5.

scalar field/potential [x^2/100 + y^2/100 -1] [Plot the grad]

# of arrows in each direction [10]

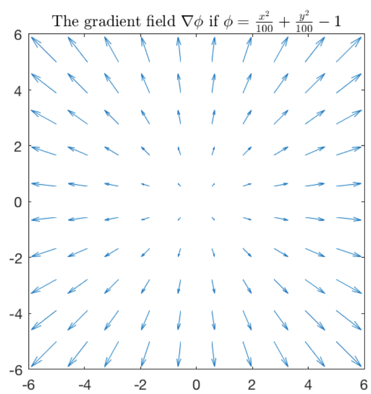


Figure 1. A snapshot of the livescript developed to accompany a homework problem on velocity field and volumetric pressure.

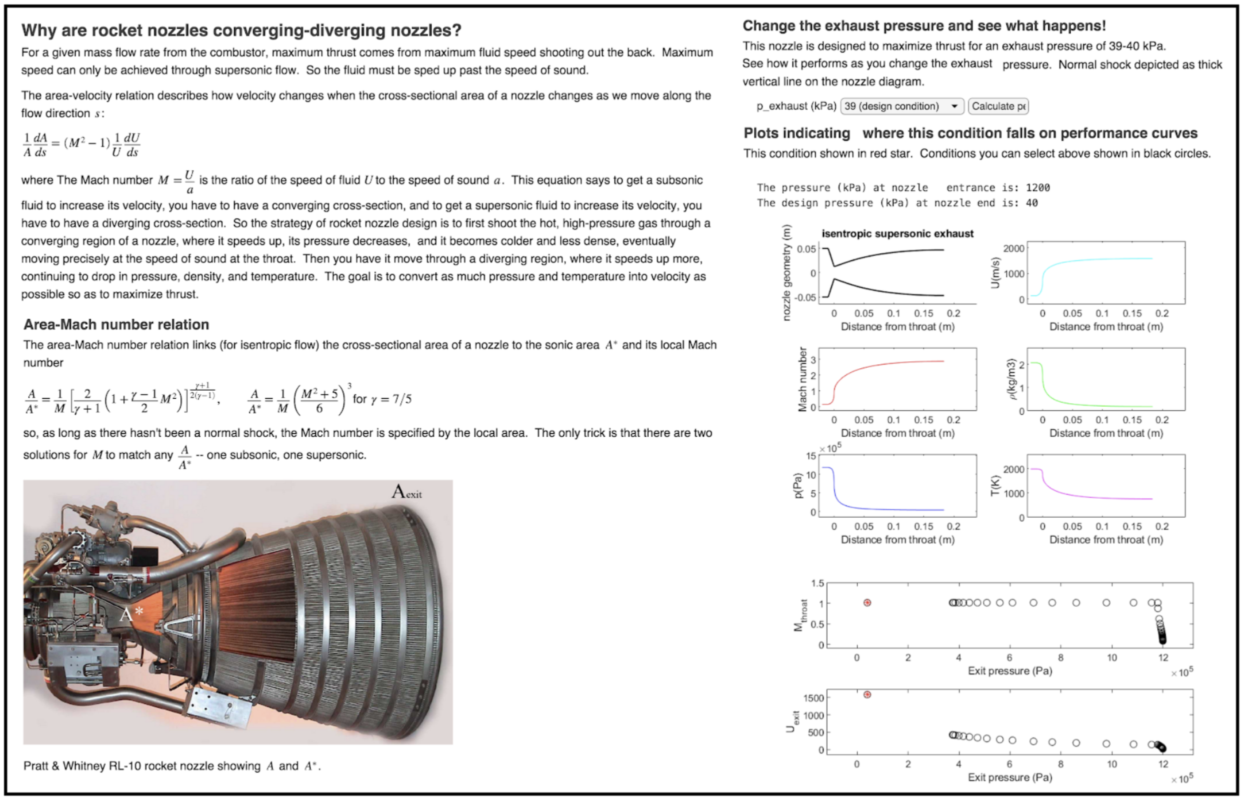


Figure 2. A snapshot of the livescript developed to accompany a homework problem on rocket nozzles.

The Stream Function and Streamlines

A stream function is a scalar quantity that can be defined for 2-D incompressible flows. It is useful primarily as a result of the fact that curves on which a stream function is constant are by definition streamlines of a 2-D incompressible flow. A stream function for a 2-D incompressible flow can be defined using the following properties:

$$\frac{\partial \psi}{\partial y} = u$$

$$-\frac{\partial \psi}{\partial x} = v$$

where u and v are the x- and y-components of the velocity field, respectively. The streamfunction only has meaning in terms of its derivatives, so adding a constant to a stream function does not change the resulting flow.

Plot the streamlines of a stream function of your choice

Type in the stream function of your choice in the box below, written as functions of x and y, and the graph will plot isocontours of the stream function, which are streamlines of the flowfield. Arrows representing the velocity field are also plotted on the graph to illustrate the direction of fluid flow. The contour colors go from blue to yellow as the value of the streamfunction increases. Note: the graph will fail or plot weirdly if you define a function that is not differentiable or well-defined on the domain -5<x<5, -5<y<5.

streamfunction [y+atan2(y,x)] [Plot the stre]

\# of streamlines [50]

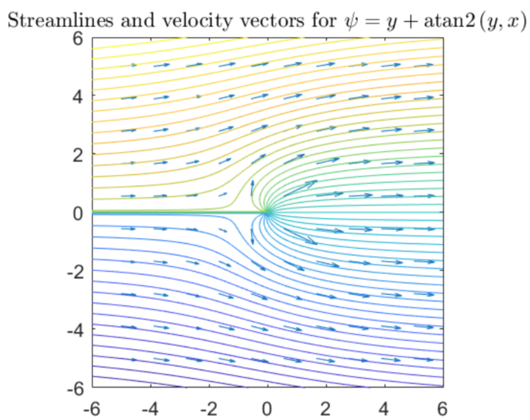


Figure 3. A snapshot of the livescript developed to accompany a homework problem on streamlines.

3.1. Scavenger hunts:

The next new component of the course in the Fall 2020 was a set of weekly team-based scavenger hunt missions using a mobile application called goosechase [8]. In this application, we described and progressively released a set of weekly missions that allow student teams to accomplish and gain reward points. Student teams are allowed to submit a photo or a video evidence in addition to a brief textual caption. The submissions are viewable by all other participating teams through a "feed page" that does not allow *commenting* but allows *likes* (or "thumbs up"). Our goal in using this platform was manifold. It served as a means to more closely engage students with the course material outside the classroom since we ask them to look at the everyday objects and processes around them through a fluid mechanical lens. This activity also served as a way to foster a sense of class level community since students shared their creative and at times artistically expressive solutions. We incentivized students through both a grade point related, and a non-grade point related reward system - see appendix. Scavenger hunts also created many opportunities for the instructor to connect the classroom discussions with students' submissions and the thinking behind them. Overall we received 1072 submissions from 25 teams, one of which was formed by the members of the instructional team, with an average number of approximately 42 submissions per team.

Overall we had seven types of missions as shown in Figure 4 (top row). Our most frequent type of mission was about *finding* something, for instance "find a pressure regulator," "find a vortex," or "find a job description related to fluids." Despite their simplicity and ease of implementation, these missions make students aware of the wealth of engineering and natural systems all around them that they would potentially have not noticed otherwise (see the link in appendix for a selection of students' submissions) and therefore these missions helped us impart a sense of intellectual curiosity and motivation for discerning the fluid mechanical notions and principles in their own experiences. The second most frequent category of missions were *study togethers* consisting of "work on MAE3230 with other classmates" and "go to office hours". Third, we had missions that ask students to *record* processes such as "flow induced oscillations" or "a bird in stall". Fourth, we had *weekend bonus* missions that gave students an opportunity to share something unrelated to the class, such as "Pet Pics! Nature Pics! Animal Pics! Zoo Pics!". Fifth, we had missions that required students to *demonstrate* phenomena such as "a Torricelli Tank" or "buoyancy in a granular system". And finally, we had two more involved missions, one to "build a Heron's fountain" and the other to "create a design for MAE3230-themed swag".

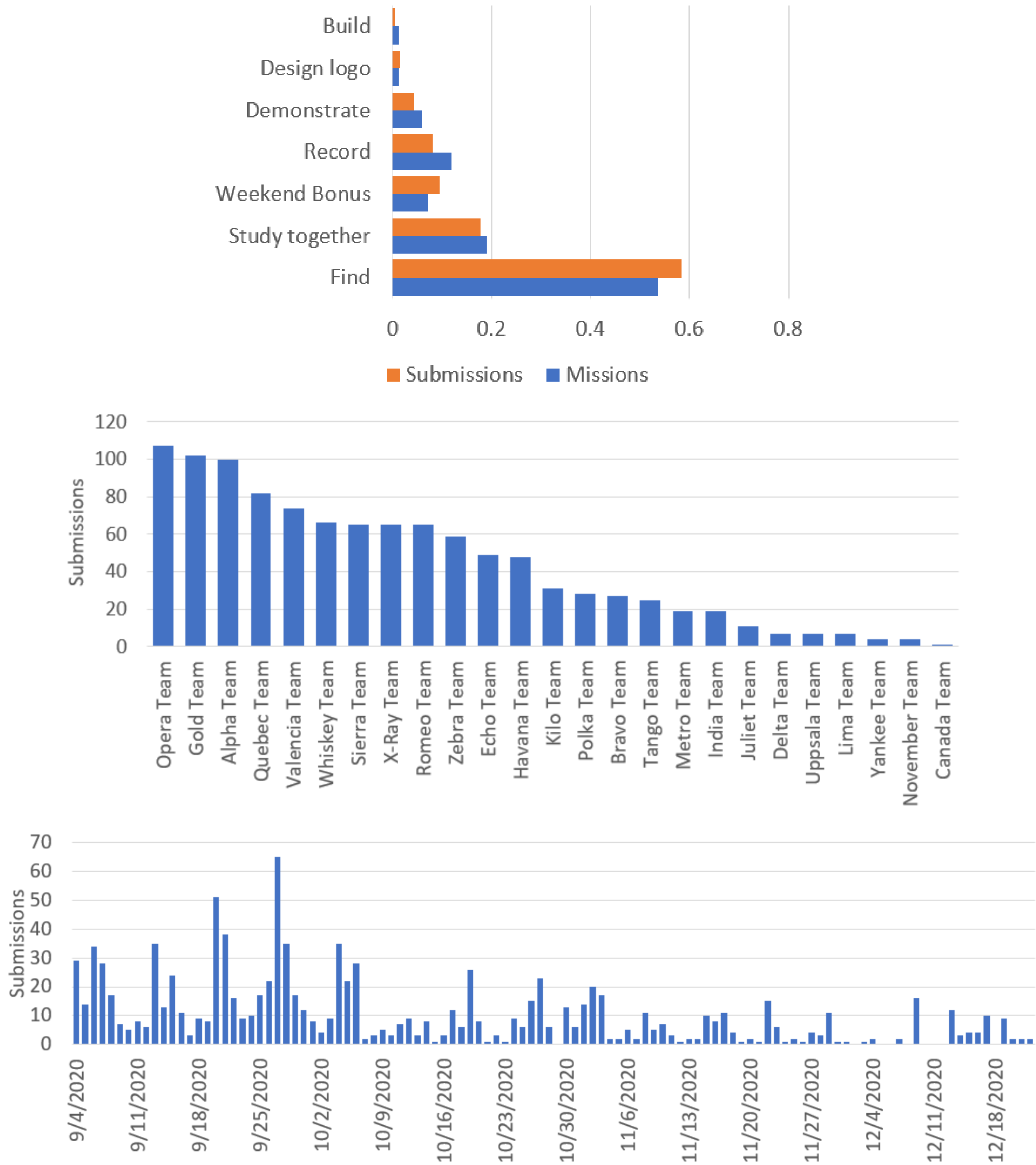


Figure 4. The top row shows the normalized number of scavenger hunt missions assigned in each category as well as the normalized number of submissions. The middle row shows the number of submissions per team. The bottom row shows the timeline of student activity in the semester.

3. Measures of Students' Performance and Attitudes

Our team has developed a multiple choice learning assessment for fluid mechanics and other engineering courses [9] which we used in our courses at the end of each semester. Figure 5 shows a comparison of the total scores for students taking the fluid mechanics concept inventory test in the two consecutive deliveries of the course. We observe a 17% drop in the mean score from 2019 to 2020 (t-test, $p \ll 0.001$).

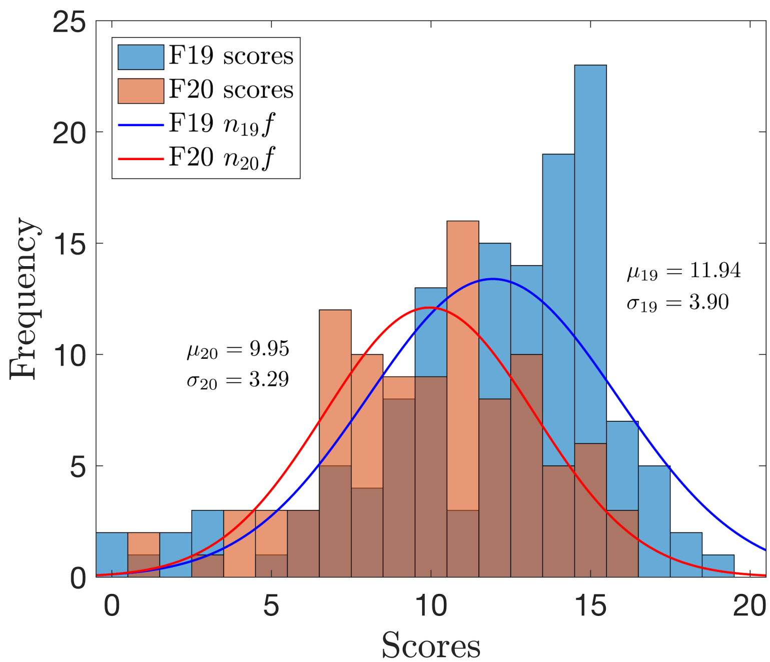


Figure 5: the distribution of scores in the multiple choice concept inventory tests ($n_{19} = 131$, $n_{20} = 99$, $f = (1\backslash\sigma\sqrt{2\pi})\, exp(-(x - \mu)^2\backslash 2\sigma^2)$.

Furthermore we measure students' motivation and attitudes towards learning by adopting portions of the Motivated Strategies for Learning Questionnaire (MSLQ) that was administered towards the end of each semester [10]. The survey included multiple items related to intrinsic and extrinsic motivation, self-efficacy, task value, and peer learning. Please see the appendix for a list of items in our survey. Figure 6 presents the results of the two consecutive administrations of the surveys at the end of each semester. Three out of six metrics included in our survey, namely the extrinsic goal orientation (EGO), lecture value (LV) and task value (TV) show an increase in 2020 while the other three, i.e. intrinsic goal value (IGO), peer learning (PE) and self-efficacy (SE) decline. In the next section we offer our reflections on the way we can interpret these results.

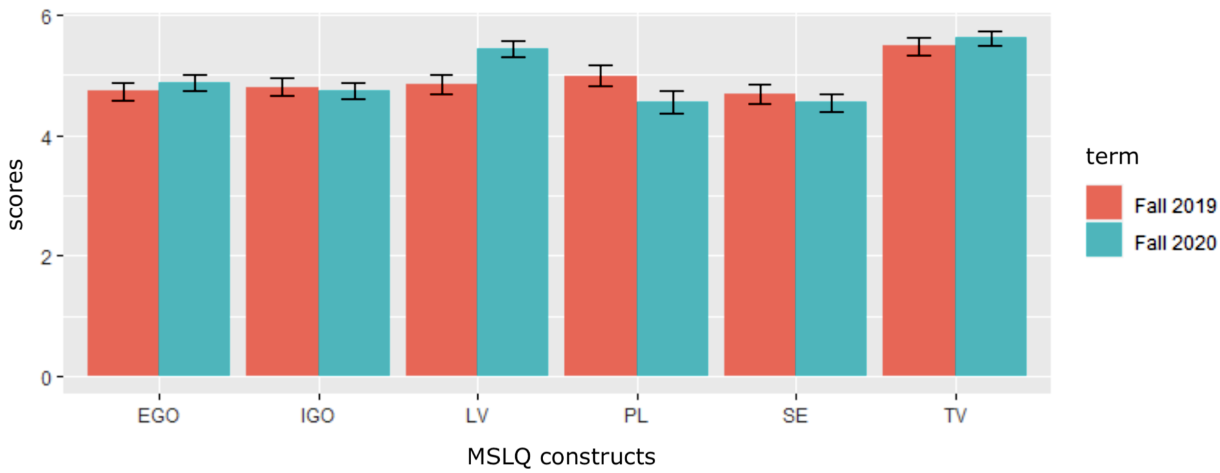


Figure 6: The mean and standard deviation of the six categories of students' attitudes measured in Fall 2020 and 2019. The only statistically significant change belongs to the enhancement of the (LV) lecture value (t-test, $p \ll 0.01$).

4. Discussion and Conclusions

The number of factors that change from the 2019 in-person setting to the 2020 online environment, in addition to the changes in the pedagogical strategies we used in the two offerings of this course make the interpretation of our data a complex task. The drop in the overall scores of the concept inventory test could be wholly an artifact of an incident that occured to our 2019 data. Since the data belonging to the 2019 concept inventory assessment was accidentally lost, the class was asked to take that assessment a second time in the Spring of 2020. While students in Fall 2020 only took this test once (as we had originally intended).

The gain we observe in the extrinsic goal orientation (EGO) combined with a reduction of the intrinsic goal orientation (IGO) could be influenced by our changes in the pedagogical strategies, or alternatively could be attributed to the fact that as a whole, students have lost many of their pre-COVID social interactions and now look at their professional future with a lesser certainty than usual. Faced with such a situation they may now be more concerned with GPA and other external targets in their learning. The statistically significant rise of the lecture value (LV) and to some extent the enhancement of the task value (TV) scores may be a direct result of the new interactive components that we adopted in 2020, or could be explained by the changes in the format of the online course. For instance, now students have all the lecture and recitation material recorded and available to them for asynchronous and personalizable reuse. Similar arguments can be levied for other observable changes in the data, many of which may deserve a more careful examination and analysis.

Going forward we are interested in expanding both of the strategies used in this course for the Fall 2021 semester. Matlab live scripts can be leveraged as classroom activities or Zoom breakout sessions. Scavenger hunts can be further used to sensitize the students on the wealth of fluid mechanical phenomena all around them and their ability to understand and articulate them from an engineering point of view. It can also help us create and sustain a culture of collegiality and positive competition in future offerings of the course.

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Appendix A. MSLQ survey questions

Extrinsic Goal Orientation:

1. The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.
2. I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.
3. Getting a good grade in this class is the most satisfying thing for me right now.
4. If I can, I want to get better grades in this class than most of the other students.

Intrinsic Goal Orientation:

1. When I have the opportunity in this class, I choose course assignments that I can learn from even if they don't guarantee a good grade.
2. In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
3. In a class like this, I prefer course material that really challenges me so I can learn new things.
4. The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.

Lecture Value:

1. I think attending the lectures for this course is a valuable use of my time.
2. I think I learn more in lecture for this class than from out-of-class readings or multimedia (video etc.) material.
3. In this class, I don't feel that I really learn anything new in lecture. [inverse item]

Peer Learning:

1. When studying for this course, I often try to explain the material to a classmate or friend.
2. When studying for this course, I often set aside time to discuss course material with a group of students from the class.
3. I try to work with other students from this class to complete the course assignments.

Self-Efficacy:

1. I'm certain I can understand the most difficult material presented in the readings for this course.
2. I'm confident I can do an excellent job on the assignments and tests in this course.

3. I believe I will receive an excellent grade in this class.
4. I'm confident I can learn the basic concepts taught in this course.
5. Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class.
6. I'm certain I can master the skills being taught in this class.
7. I expect to do well in this class.
8. I'm confident I can understand the most complex material presented by the instructor in this course.

Task Value:

1. I like the subject matter of this course.
2. I think I will be able to use what I learn in this course in other courses.
3. It is important for me to learn the course material in this class.
4. Understanding the subject matter of this course is very important to me.
5. I think the course material in this class is useful for me to learn.
6. I am very interested in the content area of this course.

Appendix B. Scavenger hunts samples

A selection of students' submissions for the scavenger hunt activities is accessible in the following URL: https://drive.google.com/drive/folders/1wtZ4IdhlOZW3ps3P63PAV9p4HWW7lH_w

Appendix C. Reward depot for scavenger hunts

Table 2. List of rewards that students can redeem by the scavenger hunt activity

Prize	**Cost (GooseChase points)**
Each person on team gets +1 point on quiz of that person's choice (not to exceed perfect score). Can be used repeatedly.	900
You get to eliminate from consideration one of the Mock Job Interview Questions	xxxx
Extend time for written exam for entire class by 15 minutes	900 points each from 8 different teams
Prof K provides a complete practice exam to entire class in preparation for written exam	1400 points each from 4 different teams
Prof K provides the solutions for the practice exam to entire class	1400 points each from 3 additional teams

Instructional staff hold a pre-written exam review session for class	900 points each from 10 different teams
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Music used in Bose noise-cancelling headphone commercials as the "noise"	3500
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: The Golden Age of Hip-Hop	3000
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: The Riot Grrrl Movement	2500
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Early 80s LA Hardcore	3000
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Sun Ra's Astro Infinity Arkestra	3000
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Lady Day	3000
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Dots and Loops	2500
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: Black Metal	3000
DJ Prof K provides Spotify playlist for your next COVID-safe party. Musical Theme: The Grunge Era	2500
Your team plays skribbl.io with Prof K and TAs	3500
Your team plays Super Smash Bros. with Prof K. Prof K. gets to play [redacted].	3500
Your team plays Among Us with Prof K and TAs	3500
Your team gets to pick a project first for Fluid-Mechanical Dissection	4000
Members of your team get one additional homework/quiz leniency	6500

Your team receives MAE3230-themed temporary tattoos	xxxx
Your team picks its recitation seats first when we next reshuffle the seating chart	xxxxx
Prof K lectures in costume for halloween	xxx points from each of 8 teams
Your team gets a private hour of office hours with a TA in preparation for written exam or mock job interview (subject to agreement between Prof K, TA, team)	xxxx
Your team picks its Mock Job Interview time slots first	xxxx
One hour of private office hours with Prof K in preparation for written exam or mock job interview. Private office hours includes as much explaining about fluid mechanics as possible. Does not imply that that team hears secrets about the exams	xxxx
One hour of private consultation with Prof K about your team's MAE3050 design project or projects (if there is one, I haven't talked to Bewley)	4000
one signed copy of the textbook signed by Prof K. Team has to share.	4000
team specifies its TikTok beatboxer, dancer, or DJ of choice -- Prof K will pursue a TikTok battle with that person. He does not promise that they will accept.	5000

team specifies its YouTube Science Communicator of choice -- Prof K will pursue a YouTube collaboration with that person. He does not promise that they will accept.	5000
Prof K joins your team for one covid-safe Trivia Night chosen to mutual convenience; you win because of his Trivia Night superpowers.	5000
one signed copy of "[name of the book redacted]" by Prof K. Team has to share.	6500
one signed copy of "[name of the book redacted]" by Prof K. Team has to share.	11000
your team selects one Friday class to cancel--which means Prof K still shows up and has an office hours/Q&A session but the lecture is canceled. Subject to Prof K approval	12000
unlock MAE3230 bonus content: Pump Selection	2000
unlock MAE3230 bonus content: Thrust Bearing	2000
unlock MAE3230 bonus content: Electroosmosis	2000
MAE department instructional staff build and demonstrate a Rubens tube for semifinal period	xxxxx
Prof K launches a vortex ring that goes from one end of Duffield Hall to another	xxxxx
Opt out of the exam or project of your choice	100000