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An Attempt to Gamify a first course in Thermodynamics

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An Attempt to Gamify a First Course in Thermodynamics

Abstract

The first course in thermodynamics has traditionally been a challenge for students in engineering programs. The course typically introduces students to concepts of energy and continuum mechanics, both of which are novel to the students. Often, the theory relies upon still-new calculus concepts for the students. With such a dense topic, this course is most often delivered in a traditional lecture-based structure. In a program throughout 7 partner universities, this first course in thermodynamics has a reputation for being the "weed-out" course for students.

In the fall of 2013, the author took an established course having 6 lab experiments, a popular textbook, a well-evolved syllabus, and overturned the motivational structure to create a new delivery model for the course. The "Thermo-Fluids 1" course became, to students, the 7-mission "Hunt for Energy and Power". The same textbook was used in the new delivery model as had been used previously; the same laboratory experiments were undertaken by students, but students had a different approach to the workload.

Throughout the course, students proceeded at their own pace, and completed 7 "missions", each with 5 levels of performance. The first 3 levels were successively more complex analytical problems. The 4th level was a lab report based on a moderately challenging open-ended lab experiment, and the 5th level was an opportunity for the student to extend a concept based on the content of the earlier lab experiment. The concept of "Design" was built into the course in a limited, but content-rich mode through having students each propose, conduct, and report on an improved development or experiment. In this paper, the author presents the results of this attempt at "gamifying" a thermodynamics course, and illustrates this one model for bringing student-directed learning into a heavy content-based course.

Introduction

The author Jane McGonigal, in her popular book "Reality is Broken" asserts:

> *A game is an opportunity to focus our energy, with relentless optimism, at something we're good at (or getting better at) and enjoy.*[1]

We aspire to instil in our students this sort of enthusiasm for a subject, and to give students the confidence, and "relentless optimism" to work through any difficulties towards mastery.

In some cases, regrettably, what we see in our students at the end of a long, hard academic term in engineering is weariness of the subject, and a lack of confidence in their skills[2]. McGonigal describes the opposite of gaming as "depression", which she defines as "a sense of inadequacy and a despondent lack of activity" [1]. This could apply loosely to the outcomes we see in some engineering thermodynamics classrooms.

Based on the author's own in-class experience; teaching thermodynamics to undergraduate students is a challenging task given they lack the background familiarity with fundamental principles, they lack motivation in the topic, and they tend toward low engagement with the content.

When considering a student faced with their first course in Thermodynamics, even the title is unfamiliar; not a common word that students would have heard or seen in school. Research by Kesidou and Duit showed that German students between the ages of 15-16 years did not gain an understanding of the most basic thermodynamic concepts in their K-12 physics instruction, including physical examples of heat, energy and temperature[3]. While there are no comparable studies in North America, it is conceivable that the German result would apply equally well.

Since everything about thermodynamics is new to students taking an introductory course, and many of the first topics covered in the subject are not exciting (defining units, properties of pure fluids, state and control volume concepts), it is a challenge to show students that the course can be relevant to their daily lives. This has been noted by Tebbe et al. in preliminary work of assessing undergraduate engineering student engagement with thermodynamics[4]. The same observation has also been noted anecdotally by numerous authors over the years, and has been the motivation for a variety of alternative approaches to organizing the content in thermodynamics, and delivery of the material in both physics and engineering classes [5, 6, 7].

While this paper will not delve into the definitions of "engagement", a concept that is complicated to define, it is clear that we want more of it in our thermodynamics students. While Heller et al. [8] have helped to clarify the language, they have also shown that the path to achieving greater student engagement in engineering requires faculty providing an active learning environment and demonstrating genuine enthusiasm for the topic, as well as students participating more fully in activities, and interacting with peers and faculty. As faculty, we hope that our enthusiasm for teaching leads to student engagement and learning. However, the methods and context need to suit the student's background.

Patterson et al. [9] have proposed that "*…in order to attract and retain students in engineering courses, the courses must be taught in a context that is familiar to students…*" They have proposed a template based on five E's: Engage, Explore, Explain, Elaborate and Evaluate. Their work provides multiple examples of mechanical engineering applications in specific teaching content. They have not addressed the overall course reward structure, and the potential for enhancing engagement, and the benefit of the "5E's" using a more engaging context for motivation and reward.

The Original Thermodynamics Course

The current introductory "Thermo-Fluids 1" course taught at the University of PEI is one which is required to cover the curriculum established by 7 partner schools in the Dalhousie University network. The academic calendar description for the course reads:

This course introduces the engineering sciences of thermodynamics and fluid mechanics in an integrated manner. A unified approach to energy transfer in thermal and mechanical systems is presented. The course covers basic properties of fluids, fluid statics, simplified analyses of fluid motion, the basic laws of thermodynamics, and the application of control volume techniques to engineering problems. Power systems are introduced through a study of the Rankine cycle. ***Format:*** *Lecture 3 hours, lab/tutorial 3 hours.*

The course is a fairly typical one for introductory engineering, and a comparable course can be found in almost every engineering program in North America.

The syllabus accepted by the 7 Dalhousie-affiliated schools is summarized in Table 1[10]. The topics were modified in 2010 when the program was changed from teaching two separate introductory courses "Thermodynamics" and "Fluid Mechanics". The modified program imported the fluid statics and incompressible flow material into Thermo-Fluids 1 and reduced some of the depth of content in the Second Law of Thermodynamics. This allowed engineering disciplines other than mechanical and civil to require students to only take Thermo-Fluids 1 rather than both introductory courses.

Syllabus for Thermo-Fluids Engineering I		
Week	**Topics**	**Lab**
1 and 2	**Introduction** • Thermodynamic systems, control volumes, properties, and states	N
3	**Properties of Pure Substances** • The *p-v-T* Surface, Steam Tables, Equations of State and the ideal gas model	Y
4	**Fluid Statics** • Pressure-elevation relations, Manometer, Forces on surfaces, Buoyancy	Y
5	**Work and Heat** • Definition of work, Modes of work transfer, Modes of energy transfer	Y
6 and 7	**The First Law of Thermodynamics** • Enthalpy, latent heats, specific heats, applied to cycles, processes, control volumes	Y
8 and 9	**Flow of Incompressible Fluids** • The continuity and steady-flow energy equations, Bernoulli's equation	Y
10, 11 and 12	**The Second Law of Thermodynamics** • Thermal energy reservoirs, Heat engines, heat pumps, and refrigerators • Reversible and irreversible processes, basic cycles	N

Table 1: The syllabus for the original course in Thermo-Fluids 1 contained relatively typical content seen in an introductory course in the field.

In each of the 7 partner universities, the course is delivered in much the same way, with an annual check-in between program chairs to ensure that the material is being covered consistently. The single compressed course has been recognized by students and faculty as one with the highest failure rate and lowest average grades in each of the programs in engineering throughout the 7 partner schools. It is a course that would benefit from an improved delivery method.

The author has taught the Thermo-Fluids 1 course for three years and the fluid mechanics course for seven years. Through that time, the author has developed a number of open-ended lab experiments providing hands-on experience in support of the course theory[11]. The labs have included many activities that follow the 5E's approach[9], and have done so in a traditional course delivery structure. The courses have been well-received by students with a range of class sizes from as low as 35 to as large as 54 students each semester. Since this is a required course in engineering at University of PEI, the enrolment reflects the variability in annual cohorts.

In its original form, the course-work consisted of in-class quizzes on a topic-by-topic basis. The quizzes made up 40% of the course grade (5 quizzes throughout the term with a "drop the lowest" policy). 10% of the grade was earned by individual solutions of practice problems. The remaining 50% of the course grades were earned from extensive lab reports from 5 of 6 labs done through the semester. The labs were intended for students to observe and interact with the underlying physics of thermodynamics, and to apply theory learned in class to hands-on settings.

While the course material was original, and students had responded positively to the assignments, and the active labs, it seemed a struggle to encourage students to interact with the textbook, and to genuinely practice the concepts through the use of study assignments, or textbook problems.

On reflecting upon the course in its original form, the author drew from the literature related to student motivation. In particular, Savage et al. [12] had considered "deep" learning and its relationship with intrinsic versus extrinsic motivation. Savage et al found that "extrinsic" motivation is the current model that students indicated was predominant in their courses. Savage et al also noted tension between teacher and student when the modes of assessment were not clear to students. Deep learning requires a transition from "extrinsic" to "intrinsic". In order to support deep learning, students need formative assessment and revision cycles as part of their learning process.

When considering the Thermo-Fluids 1 course at University of PEI, a delivery model which could encourage intrinsic motivation, and encourage students to engage with the course material, while worrying less about a single summary assessment "for grades" was desired. In addition, the context for the course delivery model would ideally be something the students understood completely. A gaming model was considered.

McGonigal makes a strong argument for the value of inserting games into many serious activities[1]. This is by no means a new concept, having been reviewed by Thatcher in a paper arguing the potential learning benefits from gaming in 1990[13]. Thatcher likens the game experience to a simulation. In so doing, he describes the role of gaming in terms of Kolb's model of experiential learning[14]. In this concept, the learning cycle contains four parts: concrete experience, reflective observation, abstract conceptualization, and active experimentation. In Thatcher's concept, the "game" or "simulation" fills the role of Kolb's concrete experience, thus priming the learning cycle in a controlled way. The potential benefit of such a role for games as simulation is to provide the fundamental experience from which students can draw.

An alternative, and more recent, understanding of the potential for games in education is primarily in the delivery of content, rather than as a stand-in for concrete experience. This secondary view of gaming in education is represented by a vast number of recent works by authors in many fields, and a representative sample of the state of the field can be found in the topical book edited by Ma, Oikonomou and Jain[15]. In particular, de Freitas and Liarokapis describe the development of "Serious Games" for education, linking the current developments with earlier concepts[16]. While a detailed "how to" is not clearly given in the literature, there are many viewpoints that help guide gamification for education[17, 18, 19, 20].

In this modern interpretation, the gamification of learning is not about replacing concrete experiences with simulations that can be controlled. The modern motive for gaming seems to be about changing the incentives for students. A common feature of games involves "Experience points", which help tally a player's score, and enable them to "Level Up" in order to increase their status compared with other players. Thus, the role of the game is in encouraging players to undertake the tasks in order to gain points, not having the tasks themselves as central to the game as was indicated by Thatcher[14].

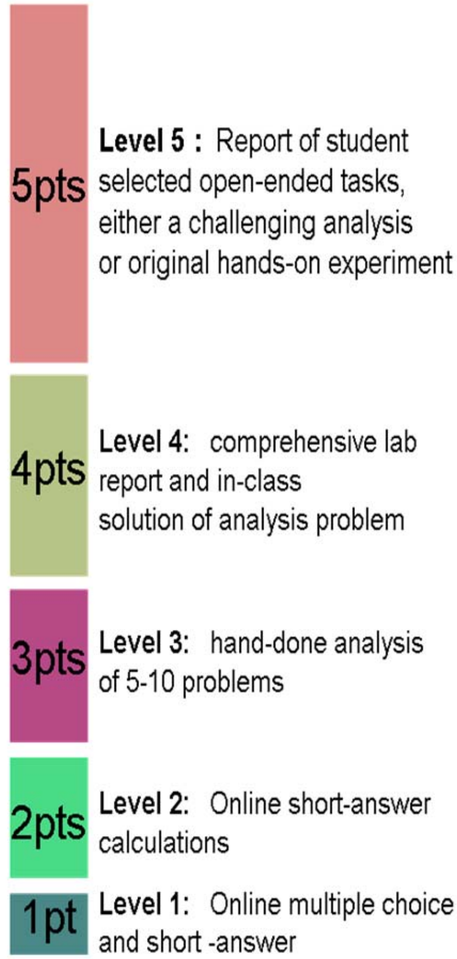

Figure 1: The concept of levels was consistent for all 7 missions. Students completed one level then moved a level-up to work through a progressively more challenging task.

Gaming Strategy

The modified course was designed to motivate students to contact the course material at their own pace, and use the model of game levels of increasing complexity and challenge. The model was similar to ones described by Goehle[20] and by de Feitas[19]. In those projects, there were visual and software elements of a video game, such as unique graphics, and increased "powers" available to players as they gained experience points. In the Thermodynamics game described here, the author did not attempt to build a custom game platform, but built the game into existing course management software, Moodle. The basic intent was to use level-up challenges to lead students to read and understand the textbook chapters, then to have them complete short calculation problems, followed by progressively more complex problems. The higher levels were carried out with active labs and research reports. Each level will be described in detail. Figure 1 shows the common features of each level.

The model for the course was presented to students on the first day of classes, and was outlined in a course syllabus on the course management site (Moodle). When asked for thoughts or questions from students, there was a general positive rumbling, with no dissent. The author prodded a bit more, directly asking for concerns, and explaining that this was a new attempt. Only one student came forward with a concern: “it sounds a bit like, well, like grade school... I mean playing a game?” The class was otherwise very enthusiastic to give it a try.

Missions		Levels				
		L1	L2	L3	L4	L5
M1	The basic tools for the hunt...	1	2	3	4	1-5
M2	Ready for the hunt, Energy Properties	1	2	3	4	1-5
M3	Looking for Energy in the ocean...Fluid Statics	1	2	3	4	1-5
M4	Searching for where it all goes?...Energy, Work and Heat	1	2	3	4	1-5
M5	Never buy gas again? Conservation of Energy	1	2	3	4	1-5
M6	Following the Flow of Fluids	1	2	3	4	1-5
M7	Recycling of energy...Second Law	1	2	3	4	1-5
	Cumulative Totals	**7**	**21**	**42**	**70**	**105**

Table 2: The table shows each of the missions and levels in the Thermo-Fluids game. The columns to the right show the number of points a student can earn by completing each level. Cumulative score of all the levels is shown at the bottom.

The course grading scheme was simple: the number of levels completed by a student was directly linked to the course grade. Students, upon being introduced to the structure of the course “Got it” right away, fully understanding that they could attempt each level, and the course management software would log their accumulation of levels towards the course grade. They expressed a sense of being “in control” of their final grade.

Table 2 shows the titles for each of the missions. These missions mimic the content from the syllabus in Table 1, but each was presented using an approach of applications-first, and theory presented in order to support the challenges. Emphasis was put on making each mission relevant to the students using original fictional stories and problems with the students as characters. Whether it was fuel economy of cars, or the human digestive system, cooling of hockey rinks, topics were cast in a light of common experiences of the individual class participants.

The textbook was used as a basic resource that students were expected to read prior to each mission, and it was made clear throughout the semester that each of the missions were tightly connected to the content presented in the chapters. Relevant textbook problems were identified for the students, and these book problems were often used as in-class examples using a number of active classroom techniques.

Each of the missions had 5 “Levels”; a scheme familiar to gamers. Each level had to be completed successfully before moving to the next level. In this game-course, this meant that students had to achieve 10/10 on each level before progressing. Since they were allowed to resubmit as many times as they wished, it meant that each task was submitted, then reviewed by the instructor and resubmitted by the student, forcing students to learn from their mistakes. Students could not ignore feedback from the teaching team; rather they had to fix their work before proceeding.

The scoring matrix is shown in Table 2. Theoretically, a student could complete Level 5 activities for all of the missions to earn a grade for the course that was higher than 100%. In practice, the Level 5 activities were sufficiently challenging that very few were completed to a level of 5/5 on the grading rubric for each mission. Even with the potential for students to resubmit the Level 5 reports of their work after receiving specific feedback suggestions from the instructor, the time involved and the standard expected for a perfect report was more than most students were willing to commit.

This was not a very “fun” game. There were no engaging graphics, and there was no inter-student competition. However, Goehle[20] lists a number of characteristics required for a good levelling system. The levelling tasks for this Thermo-Fluids game included:

- Experience points which were earned by completing progressively challenging tasks,
- Level-up thresholds similar to the effort/reward grade-value from the original non-gamified course.
- The reward for levelling was purely an increment of the course grade. An early attempt to give reward badges for each level within Moodle was attempted but abandoned.
- There was no attempt to create additional “achievement” awards for completing activities.

The class schedule included three lecture hours and one 3-hour lab period. One hour per week was used for a traditional “lecture” on the theory. The second lecture period was spent by students solving example problems in groups, with peer corrections followed by confirmation of solution methods by the instructor. The third lecture period each week was presented as a “question” class. This class was an opportunity to cover areas that students identified as being poorly understood or challenging.

Clearly, progress was fundamentally dependent upon students taking ownership of their learning. Students who simply came to class without having invested in reading or trying the missions were passive and confused during class. Students who were participating in the “Game” found that the classes were directly relevant and helpful to their studies. This difference of experience was reflected in student comments at the end of the course, with feedback divided between students who thought the instructor “disorganised” versus those who ranked the lectures as extremely valuable. Evidently, only the students who kept up with the topics being covered found the lectures helpful.

Level 1

The first level in each of the seven "missions" was intended to make the students read the textbook chapter(s) relevant to the mission. The Level was entirely completed through an online quiz of short-answer and multiple choice questions. The Level had 10 questions that were selected at random by the Moodle system for each student from a quiz bank created by the instructor for each mission. Creating the quiz bank required a significant investment of time.

The multiple choice and short-answer format of questions were chosen to be challenging, with questions having correct answers that were selected from a list of equally viable-looking options. Students could re-take the quiz as many times as required, and each time their questions were potentially different. Grading was done automatically by the Moodle site, and feedback was immediate. The only acceptable result was 10/10, so it was necessary for students to keep trying.

Level 2

After completing the 10 questions from Level 1, students progressed to the Level 2 where the questions were all numerical answers to short calculation problems. The questions were similar to the end-of-chapter questions in any engineering textbook. The Level had 7-10 questions and students were required to successfully answer all of them correctly in order to move to the next Level. While the questions were the same for all students, the problems were created with randomized parameters so that no two students would see the same question with the same numerical answer.

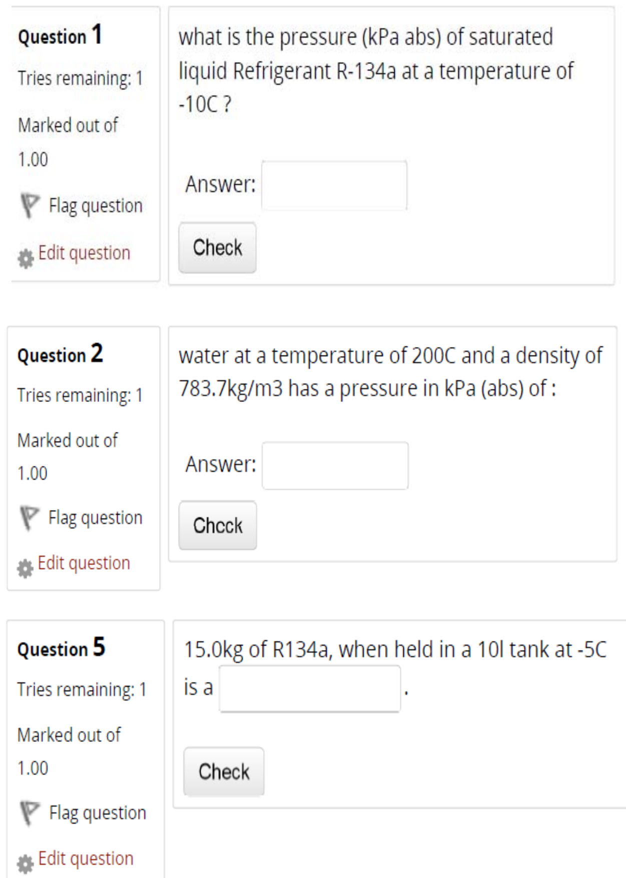

Figure 2: Example Level 1 questions from Mission 2 as they appeared to students using Moodle course software.

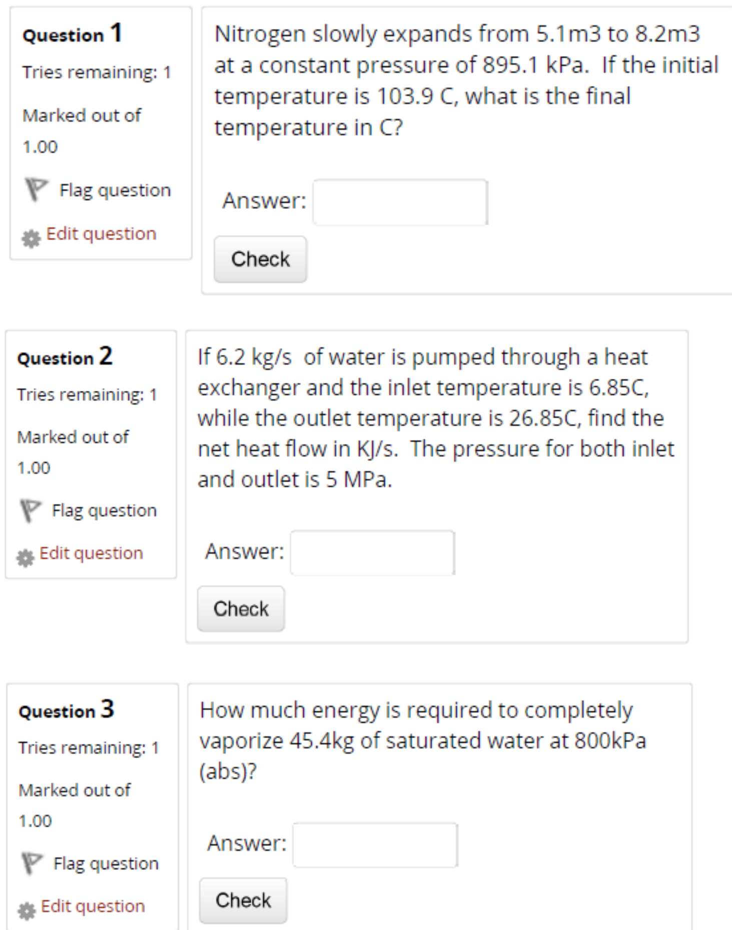

Figure 3: example questions from Level 2 in mission 2. The numerical properties were randomized for each individual instance.

The Level 2 questions were the most time-consuming to create, and were the most frustrating for students to complete. The creation of the questions required developing the question, and an equation-based solution that used randomized input parameters.

The input parameters each had to be within a realistic range, and this led to a great deal of checking and revising of questions before they were made live for students. If the student's answer was correct, the Moodle system let them know. If not, they had to complete the entire set of questions before they could re-do the attempt having errors. By the time they were able to reattempt questions, the parameters had been changed.

Student comments during the course led to several changes to the protocol, but none ended up being entirely satisfactory. In some cases, students were sufficiently savvy to write down the parameters for a particular question, and share the list with other students. In others, they simply tried multiple numerical answers.

Level 3

The third Level was a two-step challenge. It was available only after all the Level 2 questions were successfully completed. One activity was to physically conduct the experiment for the mission. A lab instruction was given for each mission providing a concise description of the experiment and the materials available. The instructions were far from being step-by-step, leaving students to think about the methods and to ask questions before carrying out the experiment.

The lab experiments were carried out in groups, and were available to students at any time they chose, depending only upon the availability of the departmental lab technician to oversee their group ensuring compliance with lab safety. If they chose to carry out the lab during the scheduled lab period, the instructor was available to offer advice and answer questions.

The only submission requirement for this Level was a brief paragraph in response to the question of "What did you do in the lab?" It was intended merely to ensure each student actually attended the lab (Figure 4).

The rest of the questions for the Level were complex analytical problems. Figure 4 shows example problems used in Mission 2. Students preferred to prepare a clear problem solution on paper and scan it into the system for grading rather than format a typed solution. The author and a student teaching assistant spent time commenting on the submissions on a continual basis, sending them back electronically to revise until the solution was acceptable. In many cases, students made 2 or 3 attempts at the trickiest problems in a mission before they were allowed to level-up.

Question 5
Answer saved
Marked out of 1.00
Flag question
Edit question

If you take a 250ml can of nitrogen at room temperature and 50 PSI pressure, then throw it on a fire, bad things will happen. Before all hell breaks loose when the can explodes, we can assume that it was heated up to perhaps 800C. a) what was the pressure inside just before it explodes, and, b) assuming the pressure rose with no expansion (assume the can was rigid... volume didn't change), how much work did it take to raise its pressure? c) how much heat did it take to raise its pressure? d) when the metal fails, the can rips open... and BOOM!!!! does it release heat or work? explain! PV and TV diagrams might be cool, as well as CV's.

Question 7
Not yet answered
Marked out of 1.00
Flag question
Edit question

An ammonia chiller system (such as some people saw at CARI) uses ammonia as the working fluid. It is a cycle which takes heat from a cool place and discharges it to a warmer place (weird, eh?). Is this because of the drastic changes in pressure in the ammonia through the cycle, or is it because of the changes of temperature, or is it because of the phase changes? could you use an ideal gas in a refrigeration system? explain... use specific examples and do calculations... include sketches.

Question 1
Answer saved
Marked out of 1.00

Please briefly describe what you saw and when you saw it, what you did, etc... This is not a lab report, merely evidence that you have actually been in lab and paid attention.

Figure 4: Example questions from Level 3 of mission 2. Students did the solutions for these problems on paper and the solutions were scanned and uploaded by the students to be reviewed and critiqued by the teaching staff.

Level 4

The fourth Level consisted of a two-part procedure. Students came to the instructor's office and requested a Level-up question in person for a mission. There was originally a set time for this during weekly lab/tutorial periods, but students were encouraged to drop by whenever it suited their schedule. Students went away and attempted to solve the problem on their own, coming back when they had completed the question(s). These questions were typically a very challenging integrative question, relying upon summary knowledge of the mission topic.

Students completed the question and brought it in-person to the professor in order for the solution to be reviewed and either accepted, or the problem areas pointed out. If the solutions weren't acceptable, students went away to improve or fix the solution and return for another review until it was deemed correct and acceptable. This interaction allowed the instructor to get a real sense of whether or not the student understood the material based on a one-on-one conversation over their hand-written solution.

In addition to the Level-up question, students had to prepare and submit a lab report from their hands-on lab carried out during Level 3. The expectation for the report was that it should accurately explain what happened during the lab. The reports were submitted online through the Moodle site. The labs were similar to those described by the author in a previous article[11].

A rubric grading scheme was provided for the reports and students were aware of the rubric beforehand. The teaching staff reviewed, commented and provided a rubric grade for the lab report. If the rubric score was not 10/10, students were required to resubmit a corrected report based on the feedback comments.

Level 4 was only considered complete if students had successfully mastered both the Level-up question and had submitted a suitable lab report.

Level 5

The highest Level in each mission was a task that students could choose on their own, but had to get approval from the instructor and/or lab technician if the Level required additional experimentation. This task was a complex and original piece of work unique for each mission. Each student who attempted a Level 5 task came up with the concept and worked with the lab instructor in order to ensure safety was assured, as well as asking for frequent input from the instructor. The graded portion of the activity was based on a formal report submitted online.

It was possible to receive 1-5 points for the submission, depending upon the quality of the attempt. Like any of the levels, the work for this Level could be resubmitted if a student chose to improve their grade on the Level.

Outcomes

It was originally presented to the students that this "game" was one where they could participate in any of the missions at any time once they had completed up to Level 3 of the first two missions. The first two topics, *Mission 1: basic concepts* and *Mission 2: properties* were seen as essential material for all of the other topics. Since the course was intended to be student-centred in a fundamental way, the lectures were meant to support the path chosen by students.

In reality, the course material was being developed at the same time as it was being offered, so the course material was not completely available on the first day of class. The students, in some cases, were at the author's office door asking for the next mission to be uploaded so they could get started on it. It was a remarkable experience having undergraduate students pushing faculty for more work.

Mission 1 covered basic background concepts of control volumes, states, properties, and processes. In particular, the concepts of systems of material versus control volumes were presented. For the lab activity, students participated in a tour of a nearby chiller plant in a hockey arena, observing the ammonia cooler system for a multi-ice surface facility that had multiple heat sinks and noting measurements from the process instrumentation. The system was complex, and the students made efforts to understand and follow the maze of pipes present in a real working thermodynamic plant.

The levels in the first mission were created for students to first answer questions related to the textbook, then further simple concrete calculation problems using material in chapters 1 and 2 of the course text. As they progressed to Level 3, they were expected to draw sketches of system control volumes and upload scans of their work to the course Moodle site. There were several technical problems encountered in the Moodle set-up of the online questions, including problems that resulted in students submitting their scanned work several times in order for it to be accepted. While this caused some concern, the students were remarkably forgiving, and remained committed to carrying on with the experiment.

Later missions also showed problems. The most challenging ones were in the Level 2 questions where the particular numerical parameters were randomly varied so that each student encountered different numbers requiring they entered different correct numerical answers. There were issues around the acceptable error between the student submission and the system's correct range of numerical answers. For three of the mission levels, this resulted in some students resubmitting as many as 19 times before the system acknowledged a correct answer. Even through this obvious frustration, the students continued to support the approach.

Student Engagement

Anecdotally, the students who were most engaged in the course material were loudly in favour of this approach. They liked the way in which the course material was set up, and commented that it was very suited to their schedules. In a program where students were taking 5 or 6 heavy technical courses each semester, it was expressed by several of them that this course was flexible... they could complete thermodynamics work during periods when their other courses were lagging. The engaged students liked the feeling of control of the pace of the course. The students who procrastinated, despite frequent encouragement (and later; warnings) by the instructor, simply said nothing until the last week of the semester.

Figure 5 shows the attempts by students for two levels in the second mission after the mission was made live. Since there were no deadlines on any activity, it was up to students to decide when to complete the tasks. The Level 2 tasks were online and received automatic, immediate feedback. Students started these tasks comparatively quickly, with 50% of the attempts made within the first week. The questions were not easy, and data from the Moodle software showed that each attempt took students approximately 1 hour to complete.

Figure 5 also shows the time line for attempts of Level 3 in mission 2. This was a set of 7 questions that required several pages of hand-calculation and upload of the sheets. It took three weeks for as many as 1/3 of the attempts to have been started. There were a large number of students who delayed even longer, as can be seen in the figure. With no deadlines, there were many students who procrastinated.

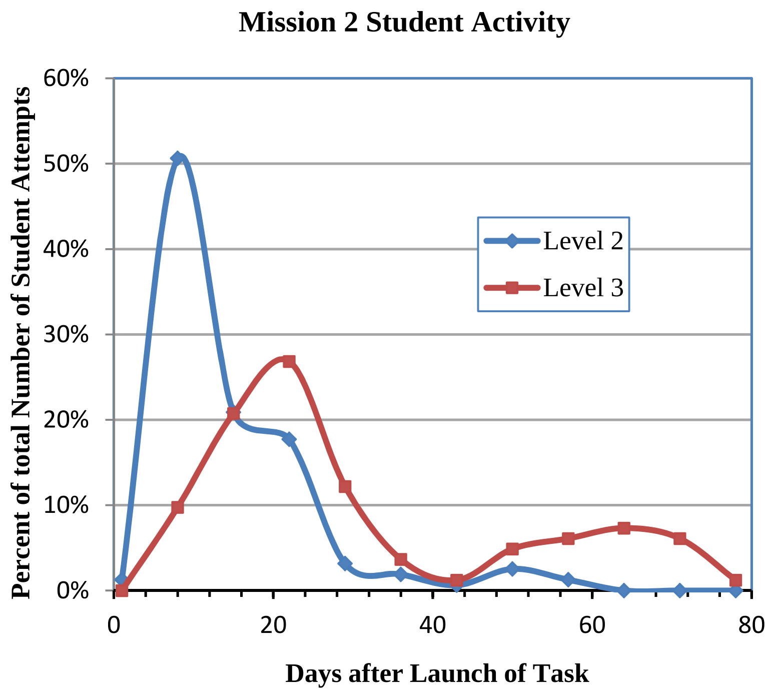

Figure 5: The time that students started tasks was up to them. The figure shows the start time of mission 2 tasks in days after the mission was made live.

Reviewing each piece of work was relatively quick, simply a scan of the submitted pages revealed whether or not the student had answered the question adequately. If there were errors or omissions, it was easy to comment on these and tell the student to resubmit. Instructor feedback took anywhere from a few hours to several weeks for student's work. For some students, there was a poor notification system that certain work had been submitted and awaited review. This was especially true for students that were working on missions that were a few weeks behind the intended flow. Thus, students who procrastinated were also victim to a long delay for feedback.

Workload

The course management software enabled tracking of the activity of students. Table 3 shows the number of attempts and the successful completions in each level. The course enrolment was 42, and, as one would expect, not all students were fully engaged in the course. The course grading scheme enabled students to finish the course with a grade of 70% if they completed all the missions up to and including the Level 4. Doing so meant that students had to **correctly** complete the work, and have a face-to-face discussion with the instructor about their solution of a problem in each of the 7 mission topics. Many students were satisfied with this grade, knowing the result simply by tabulating how many missions and levels that they had completed. They could (and many did) decide upon their desired grade, and budget their time accordingly to complete the minimum number of missions to achieve that grade.

While the number of students who attempted the levels was very high at the beginning, as can be seen in the Table 3, not all students were successful. Since the higher levels in each mission were only accessible to students who were successful at all of the lower levels, it was expected that the numbers would be lower moving to the high levels to the right of the table. In addition, moving down the table shows an approximate progression in time from the beginning of the semester to the end. The final missions were attempted by the students who had successfully completed the earlier missions with plenty of time to continue on the course-work.

Students that attempted/successful					
	L 1	L 2	L 3	L 4	L 5
M1	42	42	36	38	16
	42	42	41	42	16
M2	42	42	30	25	8
	42	42	39	34	8
M3	40	39	34	26	9
	40	39	36	35	9
M4	39	39	28	18	13
	39	39	36	30	13
M5	39	38	22	18	7
	39	38	36	29	7
M6	39	38	13	15	13
	39	38	33	27	13
M7	39	38	19	8	9
	39	38	31	15	9

Table 3: For each mission, the table shows how many students successfully completed each mission (top of each cell) level compared with the number who attempted the level (bottom of each cell)

Table 3 shows that 100% of the students who attempted the first two levels managed to complete them successfully. The higher levels, to the right in the figure were difficult. The tasks were challenging, and those students who began the missions early, were able to benefit from feedback comments, in-class examples, and direct instruction from the teaching staff. They were able to use this help to correct, improve their comprehension, and re-submit solutions until their work was acceptable. Clearly, not every student did so, and the success/attempt ratio was much smaller for the higher levels. One exception was for Level 5.

Level 5 was the only task where it was possible to get a partial grade. While fewer students attempted Level 5, those who did received at least some credit for doing so.

Students who were consistently starting the missions and levels early had time to try, fail, and correct. Table 4 indicates the gross number of attempts on all the levels. The number of Level 1 attempts for missions 1 and 2 were over 200, or an average of 5-7 attempts per student. At the time, the mission activities were new, and a number of technical issues resulted in a great deal of wasted effort on behalf of the students. Even still, they maintained an enthusiasm for the experiment and a willingness to carry through. The same was true of the Level 2 activities in missions 3 and 4; there were a small number of questions in the problem bank of questions with coding problems and technical issues. Students resubmitted the same answers many times before the system logged them as correct.

Gross Number of attempts for each task					
	L 1	L 2	L 3	L 4	L 5
M1	219	91	57	42	16
M2	299	158	83	34	8
M3	94	390	58	35	9
M4	94	308	66	30	13
M5	86	90	69	29	7
M6	149	90	60	27	13
M7	110	89	52	15	9

Table 4: The Moodle system recorded how many individual attempts were made on each task.

The most significant data came from a comparison of the number of successful student submissions versus the total number of attempts. The Table 5 shows the number of attempts per level divided by the successful number of students, giving an average number of attempts on each level by each single student. This data shows that, for the Level 1 and Level 2 activities, which were completely online and were graded automatically; students were doggedly attempting them, finding errors, and trying again. While it could be argued that the nature of the sort of questions was such that they could repeatedly guess, and keep guessing an answer until it was correct, this data reflects complete retries of the entire level set of 10-questions. Students incorrectly answered 1 or 2 of the questions in a level (as was tracked in Moodle) and then were required to start the entire set again. As the term progressed, students learned that it was more effective to actually try the questions once, then go back to the notes and text before trying again, studying the content before attempting questions. This is reflected in the stable number of average attempts in the later missions.

Levels 3 and 4 were manually graded by one student teaching assistant and the instructor. The students received a score out of 10 and extensive comments on what was lacking or incorrect in either the hand-done problem solutions in Level 3 or the complete lab report in Level 4. The average count of attempts per student (Table 5) incorporates those who submitted once and not again, as well as those few who did a complete job the first time. A very large number of students were submitting their work, receiving feedback, making corrections, and resubmitting 2 or 3 more times before they were finally successful, as can be seen in the average numbers.

The data shows that students, rather than accepting that they "missed" a topic through the course, were required to keep trying until they did, indeed "get it". This means that this gaming model for the course required students to genuinely master topics through attempted problem solutions, correction and study of the course material.

The instructor and the teaching assistant were both alert to students sharing answers and solutions. In fact, one class per week was structured to encourage students to work in-class example problems together. It was considered a good thing for students to share in this setting, but they were discouraged from sharing in the online for-credit setting. The game-like nature of the course meant that students actually did a high-five when they achieved a successful level-up. They were forward about sharing with their colleagues their successes, and, just as in a game, they did not willingly give away access to the next level... they understood that the level-up in a game is meant to be a challenge. The sense from the class was that sharing answers or cheating was, thus, no worse than in "normal" courses, and possibly better. The data gives no insight into the sharing of answers.

Number of times students attempted each task					
	L 1	L 2	L 3	L 4	L 5
M1	5.2	2.2	1.6	1.1	1.0
M2	7.1	3.8	2.8	1.4	1.0
M3	2.4	10.0	1.7	1.3	1.0
M4	2.4	7.9	2.4	1.7	1.0
M5	2.2	2.4	3.1	1.6	1.0
M6	3.8	2.4	4.6	1.8	1.0
M7	2.8	2.3	2.7	1.9	1.0

Table 5: The average number of attempts on each mission per student is shown. In some cases, the high number reflects technical issues, but otherwise it was evident that students made more than 2 or 3 attempts per task before succeeding.

Instructor Workload

The model for the gamified course relied upon 7 missions each with 5 levels. This resulted in 35 separate grade-able items from students. Of these items, the first 2 levels in each mission were graded automatically by the Moodle course management system. Thus, 21 separate "assignments" were left to be graded by the teaching staff through the semester. Without the re-submission aspect to this course, the number of marked assignments was consistent with past versions of the same course.

The teaching assistant was as enthusiastic about the experiment as the students, and was extremely diligent about reviewing work. He focussed on reviewing the Level 3 questions, and worked to keep ahead of the students demand for feedback. Since they were not able to proceed until they were marked correct, the engaged students were very concerned with getting timely feedback. Typically, reviewing the Level 3 submissions took time on the first submission by a student, but the subsequent ones were really "updates" and typically took less time if the student genuinely read the earlier review comments. The Moodle system allowed quick text box feedback on these pieces of work. Student comments in the anonymous surveys at the end of term made specific comments on the grading, and the amount of time spent by the teaching assistant and instructor doing so.

The Level 4 tasks were substantial in grading effort, and the majority were done by the instructor, although the Teaching Assistant also contributed significant hours to the work. These tasks were comprehensive lab reports submitted in a text/graphics submission box in Moodle. The re-submissions were not as time-consuming as the original ones since it was merely a check to see that comments made on the first drafts were actually implemented. Unfortunately, the author did not track the hours spent grading, but it did indeed exceed the hours in a "normal" course.

Student Feedback

Teaching evaluation forms were collected, as required for all courses at the University of PEI. Prior to handing out the sheets, the instructor specifically asked students if they would provide detailed opinions about the novel course structure in addition to their other comments on the instructor's performance. The survey was done on a day near the end of term when bad weather and an engineering society trip reduced the numbers in class. There were 22 sheets with detailed comments. Overall, there were 11 students who specifically expressed an opinion that they liked the game approach, 7 who stated no preference and only 4 who specifically stated they did not like the format out of the 22 sets of comments. The numbers are not statistically significant due to class size, but they give some sense to the acceptance by the students to this novel gaming model.

The most consistent request in the comments was for fixed due dates for each of the tasks. Out of the 22 comments, 14 of them specifically expressed a wish for due dates for the tasks. One student suggested that, as each mission was started by a student, there could be a countdown clock for completion of all five levels in that mission. More than one student commented that the model gave credit to students who were actually engaged and organised to do their work.

Conclusions

This experiment of delivering a content-heavy thermodynamics course using the model of a game had a number of positive outcomes. In particular, Students:

- engaged with the textbook outside of class in order to solve challenging problems,
- made multiple attempts to solve challenging problems paying attention to corrections and feedback from teaching staff,
- Understood and were enthusiastic about the tasks, and the grading format at the outset.

The course took a very large amount of effort to develop, but the results showed significant promise of achieving the aims to improve student engagement with the course content. Unfortunately, there are no standardized tests that are used in the University of PEI, or the

Dalhousie University network to enable a quantitative measure of how much student learning might have been affected. This could be an area for future work, and potential adoption of this model at other sites than University of PEI.

The “game” structure, while not very fun in this example, did still resonate with many of the students. They understood that the course was different, and would require that they actually perfect their work, rather than simply submitting and forgetting. Student comments and conversation indicated that students believed that they “Learned more in this class” than in others. They also commented that it involved much more work than any other course. This latter complaint, truthfully, is one seen by the author frequently from students, while at the same time receiving very positive teaching evaluations.

In particular, an approach to reduce the “procrastination” tendency of students will need to be considered. The additional game features that could be added to this model in the future could serve to make the workload for both instructors and students more measured. Limited time to carry out each mission would balance the workload for grading, and would prevent procrastination. It could also improve the connection for all students between the lecture schedule and their progress through the missions. In this attempt, students who were left behind due to procrastination were somewhat lost in the weekly lectures.

The concepts presented in the literature, particularly those expressed by de Freitas and de Freitas [19] and McGonigal [1] regarding the potential of games were validated in a heavy technical engineering-science course. Students spent more time, engaged more fully, and felt that they learned more through this course, even while providing useful criticism of some of the problems encountered. The scalability of the approach to large classes is an issue not discussed in this paper, but is one that will be considered by the author in future work. This “Thermo-Fluids Game” is worth trying again.

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References

1 McGonigal, Jane, Reality is Broken: Why Games make us Better and how they can change the world, Penguin, 2011, p.28

2 Trivett, D.A., Kotys-Schwartz, D.A., Cyrus, J.P., 2011, Comparison of engineering student self-confidence at two universities, ASEE Annual Conference Proceedings.

3 Kesidou S and Duit R. 1993. Students' conceptions of the second law of thermodynamics—an interpretive study. J Res Sci Teach 30(1):85-106.

4 Tebbe PA, Ross S, Pribyl JR. 2013. Measuring student engagement in thermodynamics courses. 2013 IEEE Frontiers in Education Conference (FIE) :1828-30.

5 Moreira MA and Santos CA. 1981. The influence of content organization on student's cognitive structure in thermodynamics. J Res Sci Teach 18(6):525-31.

6 Christensen WM, Meltzer DE, Ogilvie CA. 2009. Student ideas regarding entropy and the second law of thermodynamics in an introductory physics course. American Journal of Physics 77(10):907-17.

7 Clark D, Jorde D, 2004, Helping Students Revise Disruptive Experientially Supported Ideas about Thermodynamics: Computer Visualizations and Tactile Models, Journal of Research In Science Teaching, 41(1): 1-23.

8 Heller RS, Beil C, Dam K, Haerum B, 2010, Student and Faculty Perceptions of Engagement in Engineering, Journal of Engineering Education 35(3): 253-261.

9 Patterson EA, Campbell PB, Busch-Vishniac I, Guillaume DW. 2011. The effect of context on student engagement in engineering. European Journal of Engineering Education 36(3):211-24.

10 Undergraduate Studies Committee, 2010, The New Core Curriculum Design, Dalhousie University Faculty of Engineering, Appendix VIII, p.19

11 Trivett, D.A., 2010, Open-minded Labs: How Do We Embrace Organised Chaos in Order to Support Course Content?, ASEE Annual Conference Proceedings.

12 Savage N, Birch R, Noussi E, 2011, Motivation of engineering students in higher education., Engineering Education 6(2): 39-46.

13 Thatcher D. 1990. Promoting learning through games and simulations. Simulation & Gaming 21(3):262-73.

14 (in Thatcher): Kolb, D., 1984, Experiential Learning: Experience as the source of learning, Englewood Cliffs, N.J, Prentice-Hall

15 Ma, Minhua. Oikonomou, Andreas. Jain,L.C. 2011. Serious games and edutainment applications. London ;New York : Springer-Verlag London Ltd., c2011.

16 de Freitas, S. and Liarokapis F, 2011, Chapter 2: Serious Games: A New Paradigm for Education? In Ma, Minhua. Oikonomou, Andreas. Jain,L.C. 2011. Serious games and edutainment applications. London ;New York : Springer-Verlag London Ltd., c2011, pp.9-23.

17 Renaud C and Wagoner B. 2011. The gamification of learning. Principal Leadership 12(1):56-9.

18 Erenli K. 2013. The impact of gamification - recommending education scenarios. International Journal of Emerging Technologies in Learning (iJET) 8(S1).

19 de Freitas AA and de Freitas MM. 2013. Classroom live: A software-assisted gamification tool. Computer Science Education 23(2):186-206.

20 Goehle G. 2013. Gamification and web-based homework. Primus 23(3):234-46.