Student Earnestness in Online Circuit Analysis Textbook When Answer Is Available

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Abstract:

Engineering courses increasingly use online learning materials, especially in response to the COVID-19 pandemic and the growth in online classes. Online textbooks often have interactive components such as different types of quiz questions which may allow students to reveal the answer when stuck. These interactive components attempt to engage students in the reading material and course content.

But how do students actually engage when question answers are available with a click? Do students attempt to answer the question before revealing the answer? Or do students skip attempting the question and jump immediately to reveal the answer?

This paper aims to quantify the "earnestness" of student behavior in an online, interactive circuit analysis textbook over a period of one year. We measure student earnestness by looking at the percentage of students revealing answers prior to making a solution attempt. Thus, earnestness can indicate student engagement with the learning material.

We investigate how student earnestness correlates with length of time in the course (as defined by progression through chapters), length of time in a chapter (as defined by progression through the sections in a chapter), class size, question difficulty, number of questions in the exercise, and length of the textbook section or assignment.

The results show better student performance and/or more earnestness on questions with certain parameters. We compare the results to earlier investigations in similar interactive computer science books. Through this research, we aim to improve our understanding of how students engage with interactive learning materials, and what factors correlate with differing levels of student engagement, to inform more effective future development of interactive textbooks.

Introduction

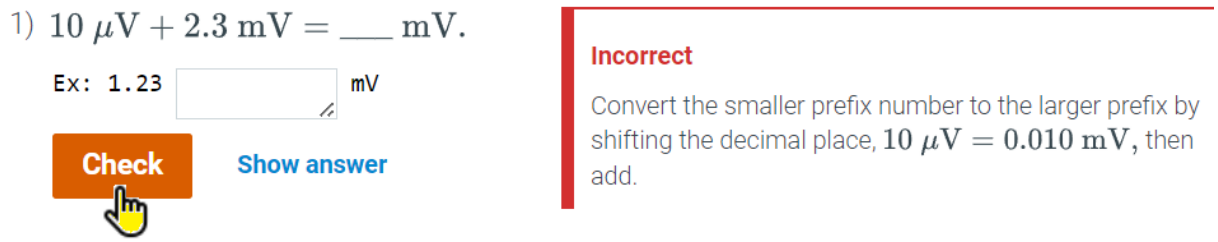
College courses often require students to spend a significant amount of time reading traditional textbook content. This leads to many students skimming or skipping the reading, hindering their learning [1], [2]. And this is despite students themselves reporting knowing that it's important to read, and that reading will improve their grades [3]. Many students find engineering courses (including introductory engineering courses) challenging, and failure rates can be high. For example, one institution found average failure rates (students receiving a grade of D or E in the course, or withdrawing) of 23% for their introductory circuit analysis course [4]. Online textbooks, tutorials and courses developed by academic institutions [4], [5], [6], [7] and companies [8], [9], [10], [11], [12] often have integrated interactive components such as different types of quiz questions to engage students, because research has shown that interactive learning materials improve students learning outcomes [13],[14],[15]. The interactive quiz questions may allow students to reveal the answer when stuck. But how do students actually engage when

question answers are available with a click? In this paper, we have quantified the "earnestness" of student behavior when the answer is available.

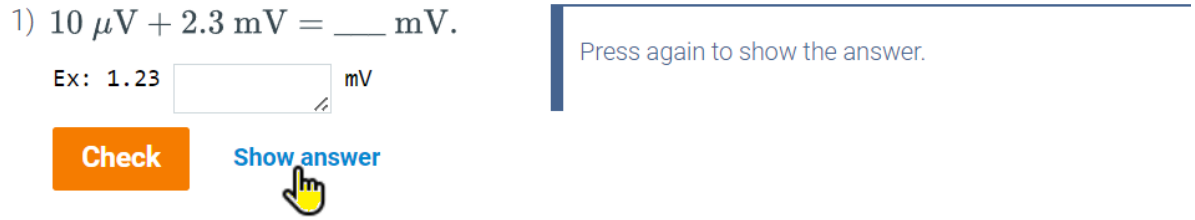
We also analyzed whether and how student earnestness correlates with multiple factors, including length of time in the course (as defined by progression through chapters), question difficulty, and length of the textbook section. We learned that there appears to be a correlation with some of the factors we examined (such as question difficulty), and not as much with others (such as length of textbook section).

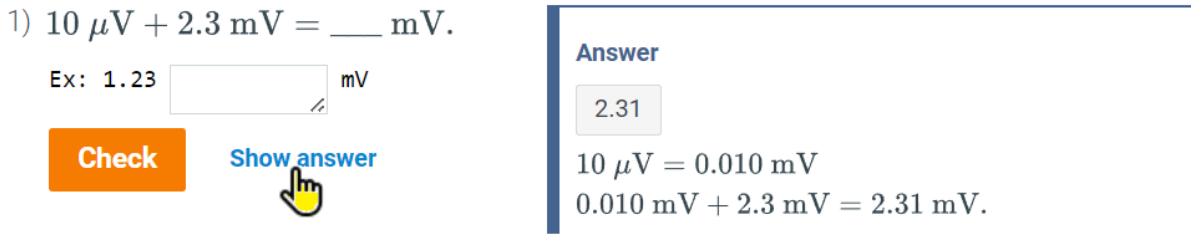
Methodology

Student earnestness for this study is defined within the context of interactive questions in an eTextbook courseware product. One type of interactive learning activity is the short answer question set, which typically counts for a portion of the course grade (by instructor choice). If the student clicks the "Check" button with no answer or an incorrect answer, the book provides a hint.



Clicking the “Show answer” button twice reveals the correct answer.





A student may attempt the question any number of times without revealing the answer, or may click to reveal the answer and then copy/paste the answer in. The student must enter a correct

answer to receive credit. Credit is awarded for the correct answer regardless of whether the answer first was revealed via "Show answer".

We defined earnestness as the percentage of short answer questions that students attempted to complete prior to clicking “Show answer” twice. A blank answer does not count as an earnest attempt. Student earnestness is defined as 0-100%, the percentage of students who responded earnestly to a particular question.

Data was analyzed for 754 students across 25 institutions, with activity from January 2022 to January 2023. Data was available for chapters 1 through 10 and 13 (out of 17), as these chapters are typically assigned in a one-semester circuits course.

Several factors were evaluated for correlation with earnestness, such as question difficulty, number of questions in an activity, length of time in course, and size of the class. The courseware platform provides the earnestness and time spent data. The authors realize that additional analysis is warranted, but this initial analysis provides guidance for further study.

We also studied earnestness versus the section number in each chapter, and for brevity provide earnestness results versus section numbers. Earnestness of all section ones, twos, etc. of all chapters have been combined. The results, presented later, indicate a trend that students are less earnest as a chapter progresses. This may result from student weariness or frustration as sections accumulate. Also, later sections in a chapter typically cover more esoteric, complicated facets of the topic.

The authors expected class size, and thus instructor-to-student ratio, would affect student earnestness. However, this study shows little initial evidence of such an effect.
Following are the results of the preliminary analyses mentioned above.

Earnestness versus progression of chapters

Figure 1 shows the box plot of earnestness versus chapter number. Earnestness is highest for Chapters 1 and 2, with averages of 68% and 61.2%, respectively, of students responding earnestly to questions. There is a noticeable drop in earnestness as the chapter numbers (indicative of more advanced subjects and progression through the course) increase from Chapter 1 to Chapter 4, with average earnestness of 53.2% in Chapter 3 and 38.9% in Chapter 4. Chapters 1 through 4 present “basic concepts”, “resistive circuits”, “nodal and loop analysis techniques”, and “operational amplifiers” respectively. These are subjects that are progressively more difficult. Anecdotally, at this point in the course term some students may drop the course and/or change majors. This drop in earnestness as the course progresses is consistent with what was observed by [16], [17] and [18].

For Chapters 5 through 13 (excluding Chapters 11 and 12, unassigned, no data available), earnestness leveled off, with average earnestness ranging from 33% to 56%. The concepts of Chapters 5 through 9 (Additional Analysis Techniques, Capacitance and Inductance, First- and Second-Order Transient Circuits, AC Steady-State Analysis, and Steady-State Power Analysis), although different than Chapters 1 to 4, are not much more complicated.

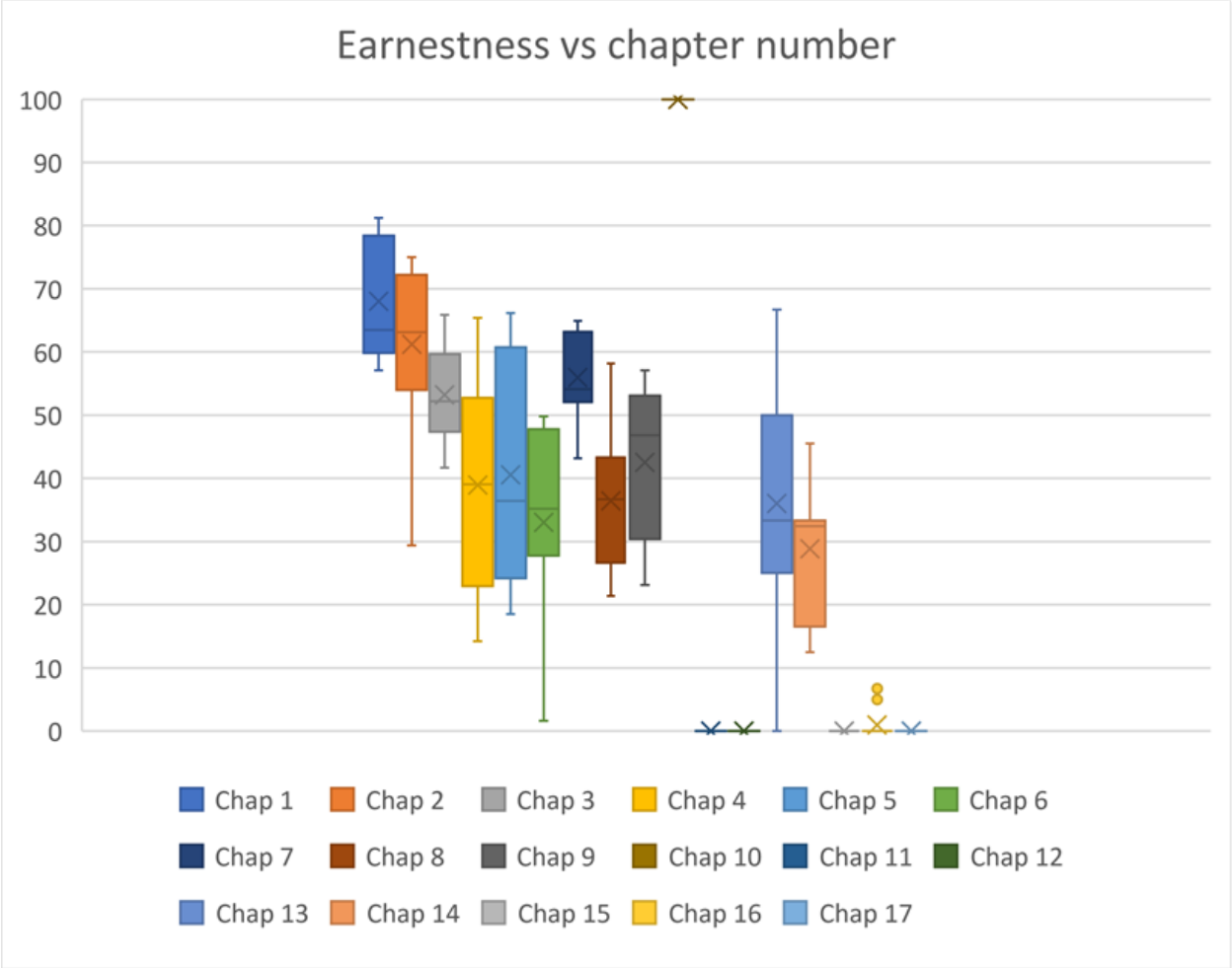


Figure 1: Box plot of earnestness versus chapter number

Earnestness versus chapters' section number

Figure 2 shows a box plot of earnestness versus section number of all chapters combined. The first four sections have almost similar average earnestness scores. Then, there is a noticeable drop in earnestness from sections 1 through 4 to sections 5 through 9. Figure 3 focuses on the average earnestness versus chapters' section number, and shows the similarity more clearly. The earnestness for sections 1 through 4 have an average of 39.0 and an average of 28.6 for sections 5 through 9. The regression lines for sections 1 through 4 is y = -1.09 x + 41.75, with the coefficient of determination (R^2) of 0.58. The regression lines for sections 5 through 9 is y = 1.66 x + 16.98, with R^2 score of 0.09. Ignoring the outlier at section 7, this score would be 0.82. Both Figures 2 and 3 indicate that earnestness does not change noticeably in the first four sections of chapters. Also, a substantial drop is observed in earnestness between the first four

sections and the following five sections, indicating a possible decrease in earnestness due to fatigue as students progress through a chapter.

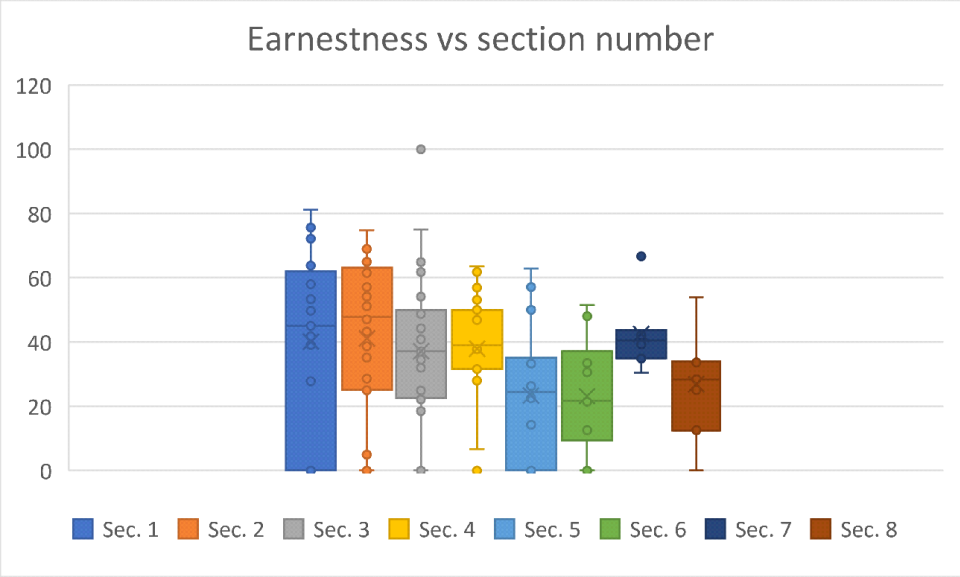


Figure 2: Box plot of earnestness versus chapters' section number

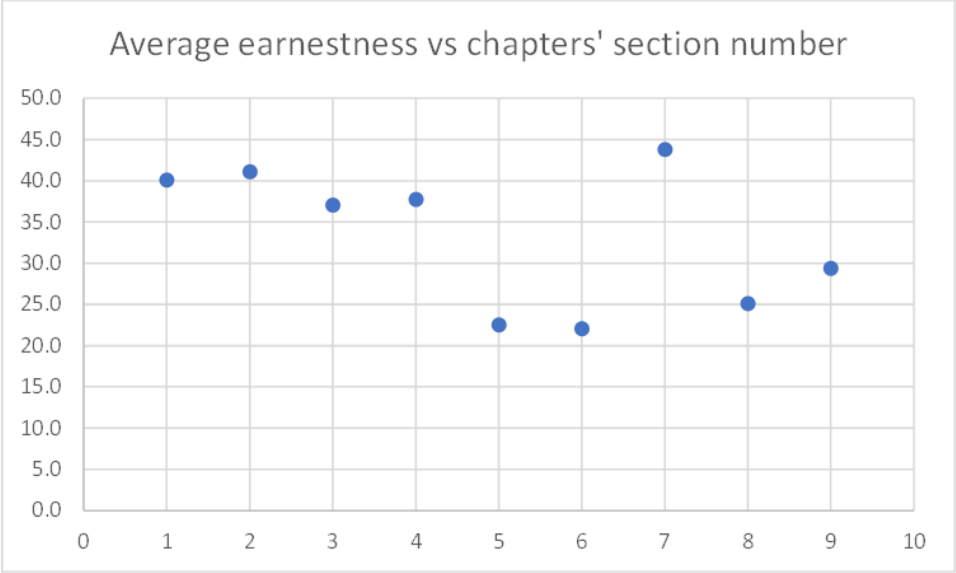


Figure 3: Average earnestness versus chapters' section number

Earnestness versus class size

It was hypothesized that class size may have an impact on student earnestness, as, for example, class size may impact the amount of direct student-instructor interaction, and consequently student attitude toward and interaction with the coursework in the form of the short answer

questions. Other research results to date have been mixed, with some studies suggesting that smaller classes are linked to stronger learning outcomes [19], [20], [21], while others found that class size has no impact on overall student grades [22], [23], [24].
Figure 4 shows the box plot of earnestness versus class sizes, grouped in multiples of tens of students. We had no information on classes in sizes of 71 to 90 students. The resulting analysis shows no significant difference in average earnestness based on class size.

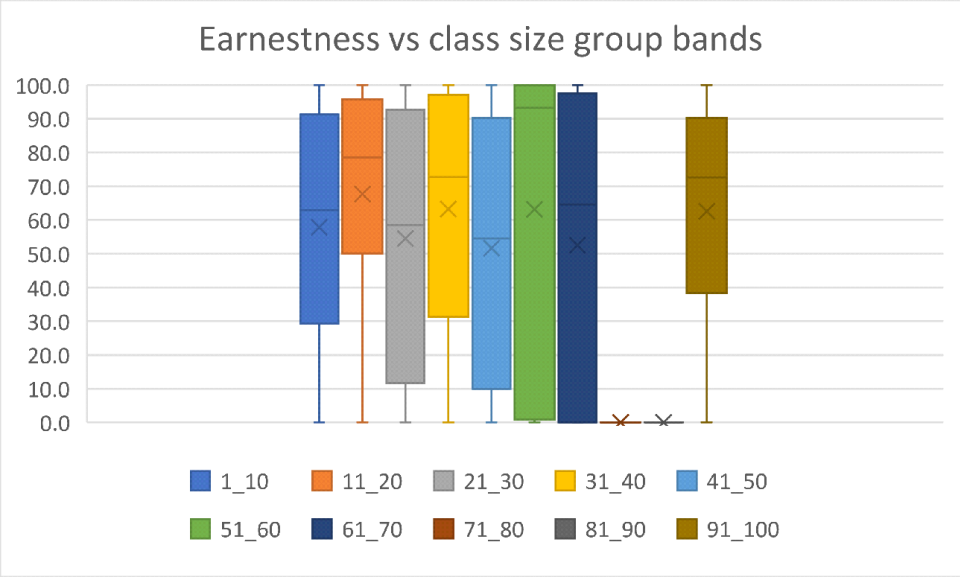


Figure 4: Box plot of earnestness versus class sizes in groups of ten

The average earnestness across all available class sizes is 59.9%. The only outstanding observation in Figure 4 is that in class sizes of 51 to 70 students there is a larger variance in earnestness, with some students revealing the answers to participation activities without trying the activities first; whereas, in smaller class sizes fewer students reveal answers without trying first. Specifically, the total standard deviation estimate of the earnestness across all class size groups is 36.5; whereas, the standard deviation estimate of class size groups from 51 to 70 students is 43.

The linear regression line for average earnestness versus class sizes of groups of single digits, 11 to 20, up to 91 to 100 with x representing 1, 11, 21, …, 91 representing the class size groups is y = -0.0096 x + 60.32. Note from this regression line that the slope is very close to zero, indicating virtually no difference in earnestness based on class size groups. The R^2 for the regression line is 0.002, a low score since the regression line is flat very near the mean, while the regression line is a good fit with the maximum residual absolute value of less than 8.2, while the mean is 59.9.

Earnestness versus question difficulty

One of the authors created many of the question sets and has taught college classes for several years using the questions. For the analysis, this author rated the question set difficulty based on the following rubric, which defines difficulty based on the number and complexity of math operations. Many students are math-averse [25], and math continues to be a barrier for students advancing [26], [27]. *The rating of each set is for the hardest question in the set*:

	Description	Example
1	**Easy**: word answer or math value from simple calculation.	How much energy is used by a 60 W light bulb in 15 seconds? Ex: 123 J Check Show answer **Answer** 900 Energy $W = Pt = 60 \times 15 = 900$ J
2	**Moderate:** math requiring two to four operations, algebra, trigonometry, or trivial calculus. If included, the schematic is relatively simple, one or two meshes	2) The energy converted to heat by a resistor as a function of time t is $w(t) = 5\sin(60t)$ J. The resistor power is $p(t) =$ ___ $\cos(60t)$ W. Ex: 123 W Check Show answer **Answer** 300 $P = \frac{d}{dt} 5\sin(60t) = 300\cos(60t)$ W
3	**Difficult**: several math operations, calculus, and/or simultaneous equations. A relatively complicated schematic: multiple meshes and/or several components.	For $L = 5$ H with $i(0) = 0$ and $v(t) = \begin{cases} 100t & \text{if } t > 0 \\ 0 & \text{if } t < 0 \end{cases}$ $i(t) =$ ___ t^2 for $t > 0$. Ex: 1 t^2 A Check Show answer **Answer** 10 $i(t) = i(0) + \frac{1}{L}\int_0^t v(x)dx = 0 + \frac{1}{5} \times \frac{100}{2} x^2 \Big\|_0^t = 10t^2$
4	**Hard**: challenging math, such as complex algebra, differential equations, partial fraction expansion. Or several simultaneous equations. Possibly	Thus $\mathbf{F}(s) = \frac{K_1}{s+3+j4} + \frac{K_1^*}{s+3-j4}$ inverse transforms to $f(t) = \mathscr{L}^{-1}[\mathbf{F}(s)] = [2\sqrt{2}e^{-3t}\cos(\boxed{??})]u(t)$ Ex: 1t-23 Check Show answer **Answer** 4t - 45 $\mathbf{F}(s) = \frac{\sqrt{2}e^{j45^\circ}}{(s+3+j4)} + \frac{\sqrt{2}e^{-j45^\circ}}{(s+3-j4)}$ $\frac{e^{j\theta}}{s+a+jb} + \frac{e^{-j\theta}}{s+a-jb} \Rightarrow 2e^{-at}\cos(bt-\theta)u(t)$ $f(t) = [2\sqrt{2}e^{-3t}\cos(4t-45^\circ)]u(t)$

	a complicated schematic.	

Table 1: Author/instructor defined question difficulty level

The results of earnestness versus difficulty are shown in Figure 5. Earnestness seems to show the most sensitivity to the level of difficulty, evident from the relatively sharp drops in earnestness with every increase in the level of difficulty. The average earnestness scores are 59.2%, 50.2%, 39.1%, and 24.5% for difficulty levels 1 to 4 respectively. Level 2 shows the largest standard deviation of 20.2% while level 4 shows the smallest standard deviation of 10.5%. Difficulty level 4 (hard) presents the sharpest drop in earnestness. [17] also observed a correlation between a reduction in average student earnestness and greater question difficulty, though their measure of difficulty was designed differently[17].

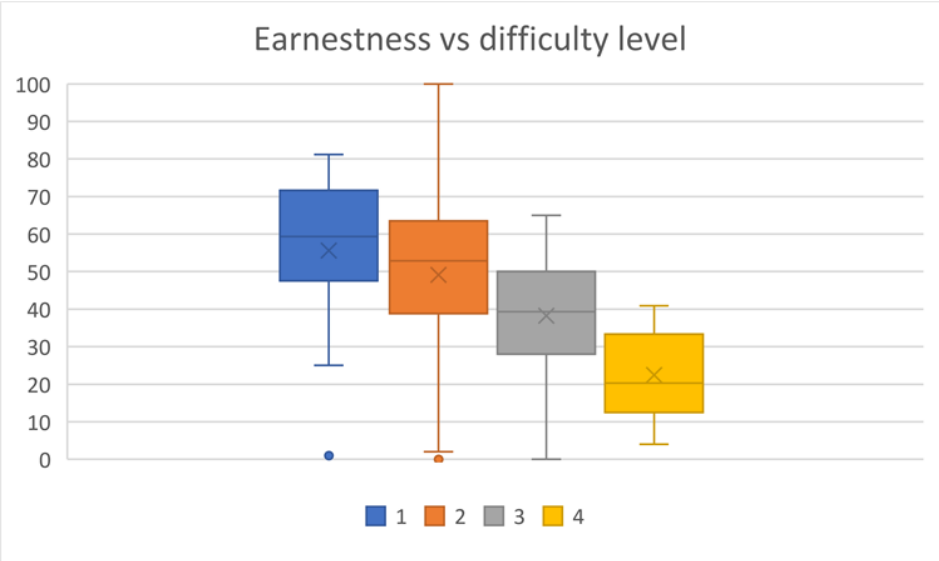


Figure 5: Box plot of earnestness versus difficulty level (1=easy to 4=Hard)

Earnestness versus section word count

Earnestness was also observed versus the relevant section's word count to see if the length of a section correlates with earnestness. [28] showed that, as textbook section length increases, the reading rate worsens. We hypothesized that increased section length would have a similar correlation with reduced earnestness.

Earnestness results were combined for sections in word count values of thousands, from 1 to 1000 (1 - 1K), 1001 to 2000 (1K - 2K), up to 14000 to 15000 (14K - 15K). The results are shown in Figure 6 as a box plot. Figure 7 shows the average earnestness for each word length group (in one thousands) along with the linear regression line.

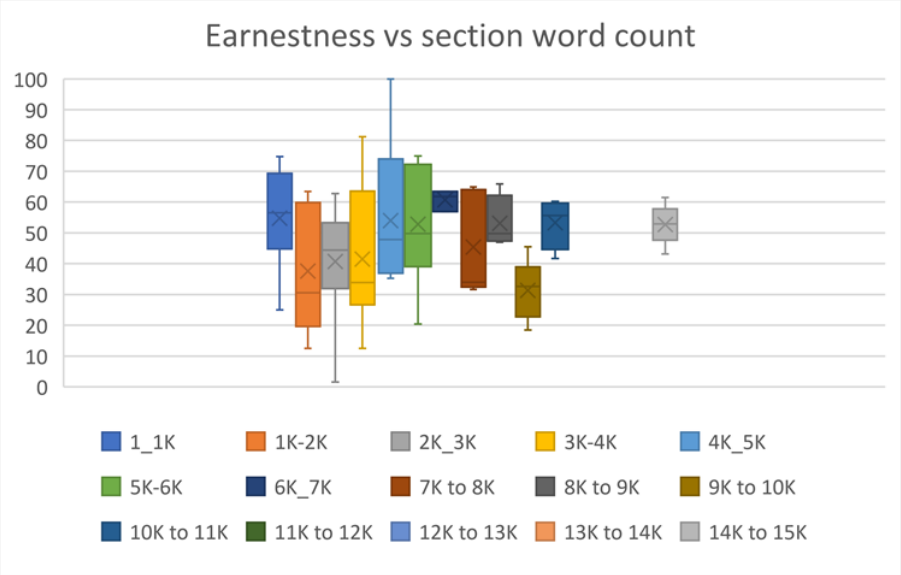


Figure 6: Earnestness versus section word count

Figures 6 and 7 show little clear correlation in earnestness among different word count groups. The lack of directional variation in earnestness based on word count is more clearly seen in Figure 7 where the linear regression line is shown for average earnestness versus word count group. The linear regression line formula is y = 0.33 x + 45.9 where x represents the word count with 1 representing group 1 to 1000, 2 representing group 1001 to 2000, etc. y represents the estimated average earnestness. Note from the formula or from the linear regression line shown in Figure 7 that the regression line is fairly flat, showing the insensitivity of the average earnestness to the section word count. The R^2 for the regression line is 0.028. Although the R^2 seems very low, but this is because the regression line is fairly flat very near the total mean resulting in low R^2 score. In fact the square root of the average of the sum of residual squares is 8.2 compared to the mean of 48.2, indicating a good regression fit.

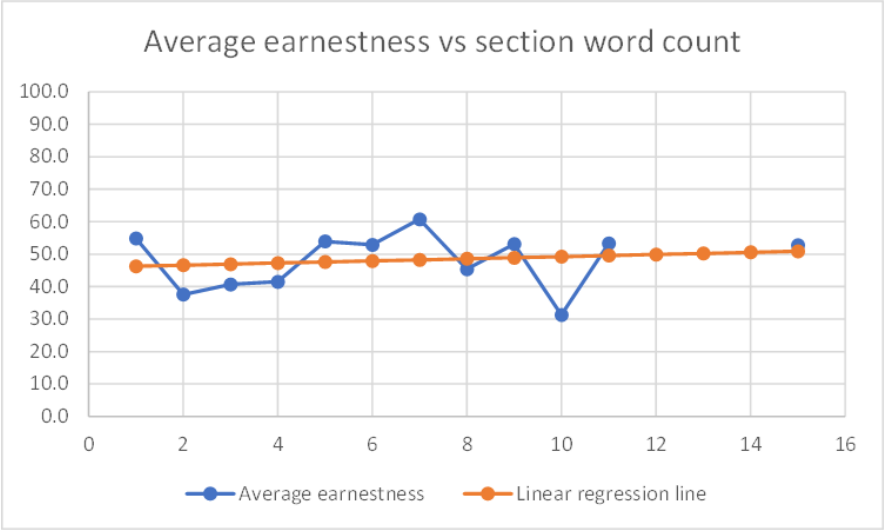


Figure 7: Average earnestness versus word count group including the linear regression line

Earnestness versus number of questions in the activity

Earnestness was also studied based on the number of questions in a participation activity (PA). [28] hypothesized that students' reading rate may increase for a section with more activities, as students may be more engaged, and may read to be able to complete those activities. [28] found that reading rate improved as the number of activities increased for two books in the study, but worsened for the third book. Interestingly, the third book had the highest number of activities per section, suggesting that increasing activities may result in increased attention only up to a particular point, past which a larger number of activities result in students feeling overwhelmed and consequently skimming and skipping the content.

The results of our analysis for earnestness relative to number of questions are shown in Figure 8 as a box plot and in Figure 9 as average earnestness versus number of questions in a PA. In Figure 8 there was only one sample for PAs with 1, 9, and 10 questions. As a result, in Figure 9 the regression line is based on the number of questions from 2 to 8.

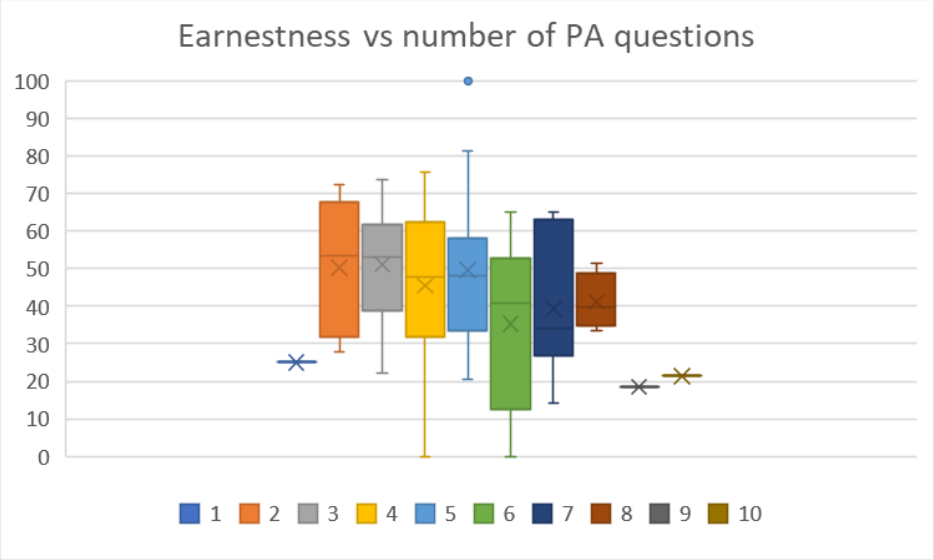


Figure 8: Earnestness versus number of PA questions

Observing the box plots in Figure 8 while ignoring the single-sample PAs (1, 8, and 9), one sees only a slight average drop in earnestness based on the number of questions in a PA. This is even more evident in Figure 9 which shows the average earnestness and the linear regression line.

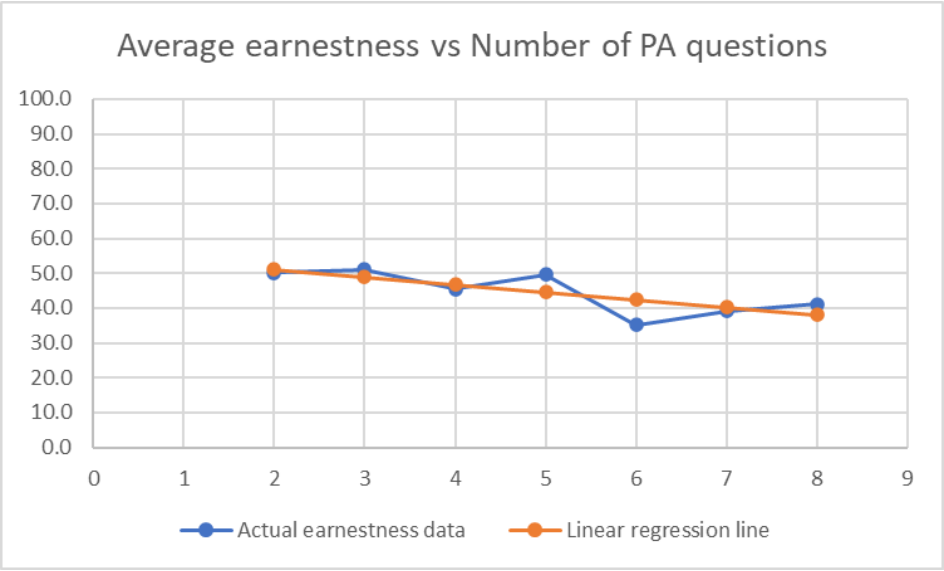


Figure 9: Average earnestness versus number of PA questions including the linear regression line

The linear regression line y = -2.18 x + 55.45, where x is the number of questions in the activity and y is the estimate of the average earnestness, represents a slight decrease in average earnestness as the number of questions increases. The R^2 for the regression line is 0.58. This effect may be attributed to fatigue or feeling overwhelmed, perceived workload as observed by [29], among other reasons. A more controlled study is needed to determine causality.

Earnestness versus question number

Figure 10 shows a box plot of earnestness versus question number of all activities combined. Activities may have from 1 to 10 questions. Figure 10 indicates that earnestness is generally similar for the first four questions, and subsequently drops for higher numbered questions, with the largest earnestness drops for questions numbered 9 and 10.

This earnestness behavior may be due to students' doing the activity questions initially, but suffering from fatigue for later questions. Another reason may be that the higher numbered questions are generally more difficult to solve. Yet another reason may be that students knowingly or unknowingly try to do activities in a similar amount of time. Hence, activities with more questions end up with lower earnestness scores for higher numbered questions. A more thorough scientific experiment is needed to determine causality.

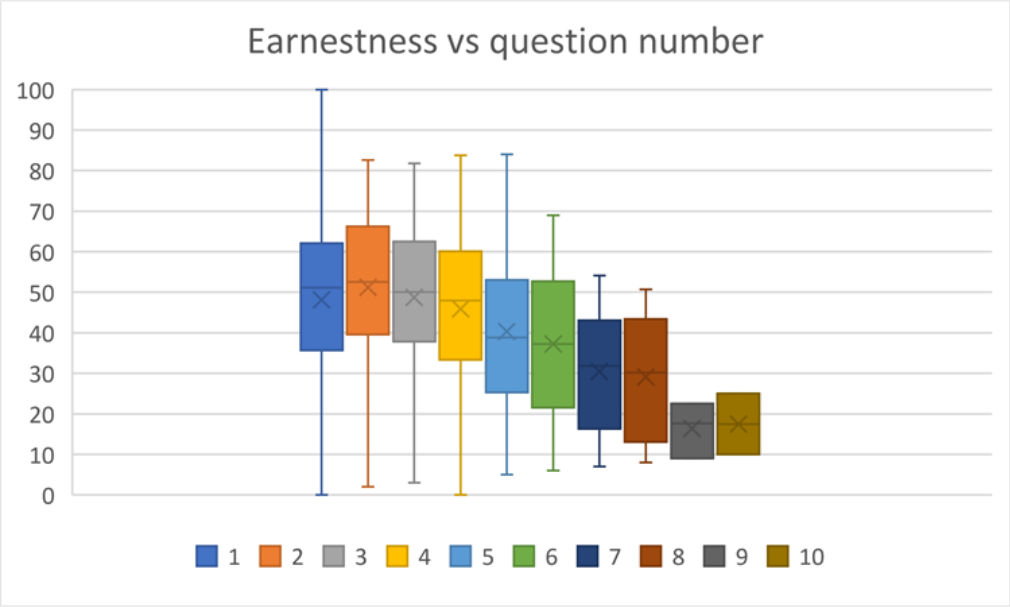


Figure 10: Earnestness versus question number

Conclusions

In conclusion, a majority of students achieve 25%-78% or better earnestness scores, depending on the chapter, even when the answer is available. Earnestness is highest in the earliest chapters, at the beginning of the course. Earnestness then decreases before leveling off. This may be a result of student fatigue as the course term progresses until students achieve a level of equilibrium that can be maintained in their coursework.

Earnestness within a chapter is highest for earlier sections and lower for later sections. This may be a result of student fatigue as they progress through the chapter.

The strongest correlation of the other factors evaluated is between earnestness and question difficulty, evident from the drops in earnestness with every increase in level of difficulty.

There was a clear drop in earnestness of activities' later questions. Earnestness is generally similar for the first four questions, and subsequently drops for later numbered questions, with the largest earnestness drops for questions numbered 9 and 10.

There was no clear correlation between earnestness and textbook section word count.

There was no correlation observed between class size and average earnestness, though for larger class sizes there is a larger variance in earnestness compared to smaller class sizes.

This paper reported students' level of observed earnestness, and analyses of earnestness correlation with various factors. Further investigation is planned into causality of these correlations, and into additional factors that may correlate with earnestness, including: student

struggle (as measured by time spent and number of attempts required for correct completion) on assessment questions for which students do not have access to the correct answer; variations in level of difficulty of questions within a set (for the evaluation in this paper, the level of difficulty for a question set was defined based on the hardest question in the set); the length of time required to perform the participation activities; the percentage of exercises completed; and the categories of the students' institutions (e.g. research universities vs. teaching universities vs. community colleges).

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