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Is the Answer Reasonable or Ridiculous? Common Factors among Students Who Display High Engineering Intuition on Technology-aided Solutions

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Introduction

Much of modern day engineering problem solving is completed with the aid of technology. While complex calculations can now be performed with minimal effort, it is essential that our students be able to evaluate whether the solution is “reasonable” or “ridiculous.” Development of this kind of “engineering intuition” is a somewhat vague, but critical, teaching goal.

Intuition is often described as subconsciously following a set of rules,[1-3] developed through experience, and leads to better decisions in complex situations.[4] In the Dreyfus model, progressing from novice (thoughtlessly following the rules) to an expert (one who examines the results) requires intuition[5] which is often difficult to teach or explain.

Transitioning from a novice to expert can occur with the help of technology. Examples such as clickers or automatic response systems, Learning Catalytics, PollEverywhere, Hotseat, and Top Hat have been shown to improve student learning.[6,7] When implementing technology, however, it is important to note whether the learning that occurs is deep or shallow. Marton and Säljö defined shallow learning as memorizing material while deep learning arises when students try to understand the material.[8] While some shallow learning is necessary, for example to learn discipline-specific terminology, most educators strive to achieve deep learning in their classrooms. Study results are mixed learning gains associated with use of technology, with some reporting shallow learning gains[9] and others resulting in deeper learning.[10-13]

Technology implementation through simulations or virtual experiments give students experiences at little cost (other than computing facilities), increased flexibility (can be completed outside of class), and greater breadth (some experiences are not feasible unless simulated). Adding virtual experiments to a class that would otherwise not include experiments can result in increased learning.[14] Virtual experiments can replace actual labs;[15] sometimes with students outperforming those who completed the in-person lab.[16] Including simulations in a course can lead to improvements in visualization and problem-solving processes.[17,18] Thus, technology can serve as a way to expedite the development of student intuition by simulating a variety of experiences within the constraints of most university courses.

An often cited goal for implementing simulations are improvements in problem-solving or critical thinking skills. Problem-solving skills and critical thinking are frequently interchangeably discussed, and the concepts are merged into a single model called reflective judgement or deliberative assessment.[19] Agreement on definitions of critical thinking are difficult if not impossible to find.[20] However, it can be broadly defined as the ability to some or all of the following: determine issues and assumptions, distinguish relationships, correctly infer and interpret conclusions from data, and evaluate evidence.[21] If used properly, simulations can enhance problem-solving skills.[22]

The effect of technology on the cognitive process has supporters and detractors. Some argue that the internet is creating a “hyperlink happy” society that is no longer able to think deeply.[23] However it is increasingly hard to ignore the proliferation of students blindly dependent on the internet, calculators, and other software for the “correct” answer. Students must now graduate with not only the knowledge of their field but also with the ability to use and evaluate technology tools that surround them. We previously found a correlation between overall GPA and problems that required information outside of class but related to prior knowledge and easily accessible via the internet.[24] Here, we further explore students’ performance on problems that “stretch” the student’s thinking to go beyond the question on the page, and to integrate their prior knowledge, draw on their experience, and evoke their curiosity. We use student success on these problems as our measure of engineering intuition, and are interested in identifying the common factors (major, career aspirations, engineering internship experience, military service, learning preferences, overall GPA, engineering GPA, and overall homework score) among students who display high engineering intuition, in an effort to better understand how we may foster this skill in all students.

Methods

Students often complete assignments without questioning if the results or assumptions are realistic or practical. This lack of assessment can be particularly true in the case of technology-aided problem solution, as we often believe that machines make fewer errors than man. The purpose of this research is to assess how students view assumptions or results in simulations that require additional information not given in class, what we are terming “stretch” problems. In this research, simulations refer to using software to solve problems where the real-life process is difficult to recreate in a classroom.

The studied classes are from two small private universities, one in the mid-atlantic and the other in the west. At both institutions, the examined courses are required junior-level engineering classes that incorporate simulations into the classroom. The class from the mid-atlantic university was a chemical engineering course on separations with a total of 21 students, and the course from the western university was an aerospace engineering course on orbital mechanics with 31 students. We chose required junior-level courses because at this stage students have basic disciplinary knowledge and have had a few opportunities to work on open-ended questions possibly pushing them further along in their cognitive development. The junior year is also key in the transition from novice to expert when students receive the last of their technical preparations before their senior capstone design courses. The use of common industry simulation software also increases course diversity and helps to push students into higher levels of development such as early or higher multiplicity. In Perry’s theory of development, this refers to when students admit that multiple answers are possible and instructors might not know the answer (a common experience in capstone design courses).[25]

Previous work done in the Fall of 2015 on the orbital mechanics class found that students who perform better on questions simulation assumptions were more likely to have internship experience or a high GPA.[24] For this research, the problems required additional steps (such as an extra calculation or searching for information online) to determine the feasibility of the results.

In addition to the simulation questions, a survey was administered to students which asked for internship experience, ideal job, and the Felder-Soloman Index of Learning Styles.[26]

The aerospace engineering course used the simulation tool, General Mission Analysis Tool (GMAT), an open source spacecraft trajectory optimization and mission analysis tool developed by NASA and private industry.[27] Since its initial release in 2007, GMAT has gone through multiple versions and been used by the research and industrial community. The aerospace engineering course, in addition to the survey, had an additional question on the results of a simulation on three of the ten required simulation homeworks. The three questions were:

1. If the goal of the mission is to do a lunar fly-by and someone proposed this mission, would you approve it? Why or why not?

2. If you were planning this trajectory, would you be worried about the lifetime of the spacecraft? Why or why not? What if the trajectory had the same altitude around Earth?

3. If the goal of the fly-by was to fly in-between Saturn’s rings, would you have the spacecraft perform this fly-by? Why or why not?

The chemical engineering course used Aspen HYSYS and Properties from AspenTech for simulations. HYSYS is plant simulation software, while Properties is a database of thermodynamic information. HYSYS is commonly used in chemical engineering senior design courses. Similar to the aerospace class, additional questions were included on three simulation homework problems throughout the term:

1. At the pressure you selected, can you achieve this separation? If so, how many stages are required? If not, how would you modify the operating conditions to make it possible?

2. Under the specified conditions, would you recommend this design for an absorber? Why or why not?

3. Would you recommend this column design? Look at the column holistically, and fully justify your response.

We chose these simulation questions to take a homework problem from a theoretical assignment to a real-life scenario. The open-ended questions forced students to not only have an opinion about their solution but also search for information not presented directly in the problem. Question solutions were not always readily apparent, but students did have the tools to reach the correct answer or recommendation. The questions required understanding what was critical to truly evaluating the scenario, and searching for additional information that was readily available on the internet (i.e. the size of Saturn’s rings) or easily calculated from prior knowledge. The questions were evaluated on the yes/no response or recommendation and the rationalization behind the choice. The “correctness” of response (yes/no recommendation) was marked as no answer, correct, or incorrect. If the recommendation was correct, the reasoning of the answer was found to be correct or incorrect. In this paper, we define “correct answer” or “correctness” as the yes/no recommendation and “correct reasoning” or “reasoning” the validity of that choice. The three questions spanned the semester to account for variation in difficulty. As concepts become more complex throughout the semester, more distinct differences may be observable between students with high engineering intuition and their classmates. Student responses were collected, coded, and analyzed for correlations between correctness and reasoning with the following factors: learning styles, internship experience, overall homework grade, course grade, overall GPA, STEM GPA, and engineering (ENGR) GPA. We define ENGR GPA as the GPA calculated specifically from courses within the engineering programs, whereas STEM GPA includes all STEM courses (such as physics, chemistry, calculus, etc).

Statistical analyses was completed using JMP software. Categorical variables (e.g., success on problem) were analyzed using Fisher's Exact Test to account for low counts in contingency table cells. Continuous numerical variables (such as final numerical grade percentage) were analyzed using non-parametric one-way ANOVA or t-test.

Results and Discussion

To properly frame our results, it is important to first provide a bit more information on the context of the aerospace and chemical engineering courses. As noted, students in the orbital mechanics class are from two different tracks (aeronautics or astronautics) as well as different class years (juniors and seniors). While these students have shared aspects of their curricular experiences, they have not taken all of the same core technical courses together. The separations course, on the other hand, is a class of chemical engineering juniors who have shared their entire disciplinary coursework. Thus, the variability in their experiences with respect to instructor and chemical engineering curriculum is negligible. This may reflect why the chemical engineering course showed no statistically significant results, and the relatively small variability in answers observed. In fact, all students in the separations class got the first problem correct, suggesting it was too easy, the second problem was largely similar, and almost every student got the correct answer with the (same or similar) wrong reasoning for the final problem. This lack of variability may stem from a highly shared curricular experience, or high degree of collaboration on homework. Neither class showed statistically significant correlations with learning preferences.

In the aerospace engineering course, homework is 35% of the final grade, and four exams are worth 45% of the grade. The remaining portion of the grade comes from quizzes (15%) and peer evaluations (5%). The aerospace engineering course is a core class for students on the astronautics track, and a required breadth class for the students on the aeronautics track. In the chemical engineering course, homework is 10% of final grade and a series of 5 exams make up 65% of the grade. The rest of student grade consists of laboratory assignments (5%), class engagement (5%), and a final project (15%). The chemical engineering course is a core course required for all students in the chemical engineering program, and taken strictly in the fall of the third year as a co-requisite to physical chemistry and a pre-requisite to unit operations.

In both courses, gaining proficiency with specific applications of the software used (GMAT for the aerospace engineering course, and HYSYS for the chemical engineering course) are historic learning objectives. As previously mentioned, these simulation programs are widely used in their respective disciplines, and their use is integrated into upper level courses to better prepare students for the real world.

In the aerospace section (n = 27), the second problem showed the greatest number of statistically significant correlations. On this problem, correct answer had a positive correlation with internship experience ($p = 0.05$, see Figure 1**)**, and correct reasoning correlated positively with measures of performance including overall GPA ($p = 0.03$), overall homework grade in class ($p = 0.001$), overall class grade ($p = 0.01$), and STEM GPA ($p = 0.0223$). Interestingly, there was no correlation with ENGR GPA.

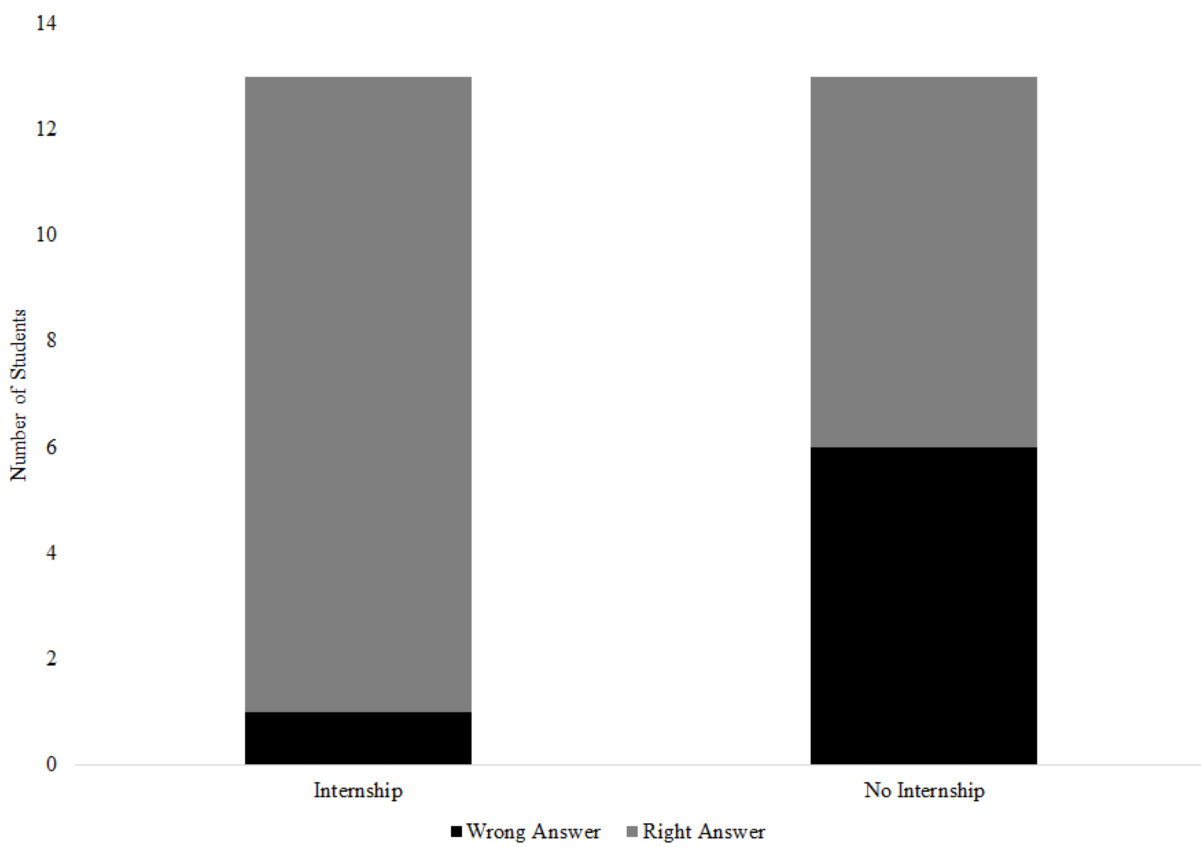

Figure 1. Comparison of correct answer and internship experience for orbit mechanics question 2. Students with internship experience more frequently answered the question correctly, while students without internship experience

On the third question, the aerospace class did show a statistically significant positive correlation with correct answer and overall GPA at an alpha of 0.10 ($p = 0.07$). There was no correlation with ENGR or STEM GPA. It is also interesting to note that compared to questions 1 and 2, relatively few students got question 3 correct, and of those only a couple had the correct reasoning. In both classes, the third question was an "extra stretch" question, students had to calculate multiple extra things or integrate several concepts to get the correct answer. The results suggest that perhaps this was perhaps a bit too far of a "stretch" for students, and the degree of "stretch" may be an important consideration when designing such problems.

The second question in the aerospace class was also used in our previous study, and similar correlations with measures of performance as well as internship experience, were observed. In that work, our sample size was two to three times larger, and we were better able to discern a trend in which high (overall) GPA students were likely to answer the question and get it correct, whereas low GPA students were unlikely to even attempt an answer (Figure 2).

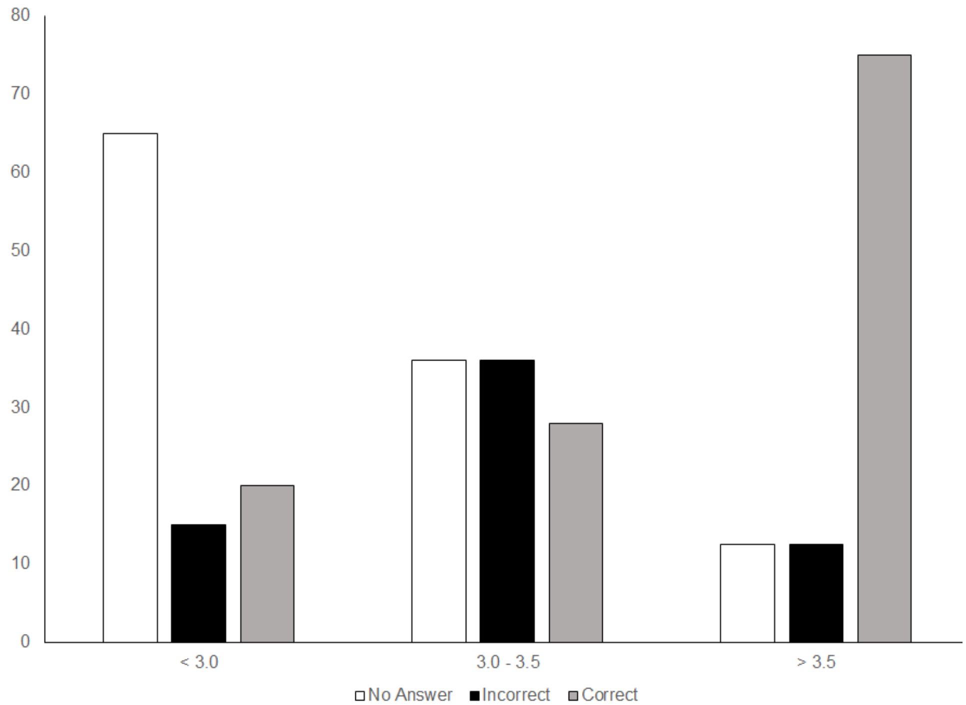

Figure 2. Student responses by GPA to orbit mechanics question 2 from previous study. Students with GPA >3.5 were much more likely to answer the question and get it correct, while students with GPA < 3.0 were unlikely to

Conclusions and Future Work

The results from the two semesters highlight that internship experience and GPA may hold key information in deciphering some of the mystery behind engineering intuition. Intuition is known to be developed through experience, thus, the internship results is not particularly surprising. However, the correlations between strong engineering intuition and GPA are quite interesting. The correlation between engineering intuition and overall GPA may be expected, but the fact that this trend holds true when STEM GPA is isolated but not when ENGR GPA is isolated fosters new questions. Further, the third “super stretch” question only showed positive correlations with overall GPA. Students with high overall GPA are successful in all of their coursework, not just STEM or ENGR. Could this be simply a high-achiever affect, or is there something greater at play where engineering intuition is linked to having a varied experience or the ability to draw information from multiple perspectives?

Future work will continue to investigate common factors among students who demonstrate strong engineering intuition on stretch problems. This requires a greater sample size, and we are now in the process of recruiting study sites across the United States. Once common factors have been established with good confidence, we will shift our focuses to understanding what the causality may be behind the observed correlations and use that information to develop and test interventions that may accelerate student development of engineering intuition.

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