AC 2011-327: CHEMICAL ENGINEERING PROBLEM SOLVING: HOW IMPORTANT IS PERSISTENCE?

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Chemical Engineering Problem Solving: How Important Is Persistence?

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Abstract
Over the past two decades, research on problem solving has focused on identifying the factors that impact successful problem solving. One factor researchers have identified is that persistence and doggedness are frequently key attributes of successful problem solvers. Some researchers have suggested, however, that as the number of distractions available to students increases (e.g., cell phones, social networking), the problem solving abilities of students will decline because problem solving persistence is not properly developed. This paper begins by examining previous research on the link between persistence and problem solving successes. Most of this research has been based on observations of students trying to solve problems in mathematics and physics. To gain additional insight into the connection between persistence and problem solving success, we examine self-reported time utilization data from both second-year and third-year chemical engineering students. Persistence is examined both in terms of the average length of time between interruptions while solving a problem and the total amount of time spent on a problem. In most cases, the data shows a positive correlation between problem solving success and persistence, but the correlation is weak and not as significant as other factors in determining problem solving success. Further, time per problem solving session is more important than the total time spent per problem in determining problem solving success for the lower-level course, but for the upper-level course, the opposite result was observed. There, the total time spent per problem was a significant variable, but time between interruptions was not significant.

Keywords: persistence, problem solving, time allocation

Introduction

The book 'Outliers' by Malcolm Gladwell explores different factors affecting the success and failures of individuals[1]. For example, he describes how successful junior hockey players in Canada are more likely to be born early in the year (e.g., in January or February) because the age cut-off at each level is December 31. A number of the factors he identifies that play a role in success are outside the control of an individual (e.g., the date of your birth or the location of your first home) but other factors can be controlled (e.g., The amount of time spent practicing the cello --- hint, you need 10,000 hours to be a world class at something). In one chapter, Gladwell interviews math and education professor Alan Schoenfeld. Based on Schoenfeld's research, Gladwell argues that being good at mathematics and problem solving is less an innate ability than a function of persistence and doggedness. He goes on to argue that cultures that place an emphasis on effort and labor-intensive work, such as Korea and Japan, score higher on country-by-country ranked math tests because of their historical emphasis on patience and dedication.

The question I wanted to answer while reading Outliers is whether or not Chemical Engineering students could improve their performance in college engineering courses or later at their place of employment by being more persistent when they were working on a problem. Could simply minimizing distractions while working on a problem and trying to focus for a longer period of time improve performance? Do persistent and dogged students perform better or learn more than the students that give up easily or are more distracted despite other differences related to their abilities?

This paper is an attempt to begin answering these questions for engineering students, in general, and Chemical Engineering students, in particular. The first half of the paper is focused on research by Schoenfeld and others on the importance of persistence and doggedness, and I attempt to examine whether or not this research may apply to Chemical Engineering students. The second half of the paper reports the results of two one semester experiments in which students documented how they spent their time working on homework in a typical lower-level Chemical Engineering course (Elementary Principles, also known as Mass Balances) and a typical upper-level course (Mass Transfer Operations).

Research on Persistence and Problem Solving

Research into successful and unsuccessful problem solving has been ongoing for many decades, especially in the field of mathematics (e.g., see Polya[2]). An early consequence of this research was to incorporate the teaching of problem solving skills into upper level mathematics education. Instead of just equipping students with a set of skills (e.g., how to determine a derivative), students were also taught problem solving strategies and heuristics that had been used successfully by others to help them when faced with a new problem to solve. These heuristics are now relatively abundant in most technical fields, and most problem solvers have a number of favorite heuristics. For example, "assume the solution is known and try to determine what properties it might have" is a commonly used heuristic in many fields (e.g., physics, engineering, etc.)

Beginning in the 1970's, Schoenfeld began teaching mathematical problem solving, and he started observing and videotaping students while they struggled to solve different mathematical problems. Schoenfeld identified four different components to successful mathematical problem solving performance[3-6], and they are:

1. resources – the mathematical facts and procedures possessed by the problem solver
2. heuristics – problem solving strategies or techniques,
3. control – ability to select and implement the proper resources and strategies, and
4. belief system – the perspective with which one approaches the problem even when one is not consciously aware of holding these beliefs.

Schoenfeld observed that the focus of teaching problem solving is frequently on components one and two:

> "A consequence of this perspective is that instruction has traditionally focused on the content aspect of knowledge. Traditionally one defines what students ought to know in terms of chunks of subject matter, and characterizes what a student knows in terms of the amount of content that has been mastered[7]."

However, he also observed that the barrier(s) to successful problem solving often involved components three (control) or four (belief system). For example, while observing students' problem solving performance, he observed that "the students knew a great deal that went unused because they felt that knowledge to be useless[4]." In other words, they had an incorrect belief system. Students would assume the problem was hard and they could not solve it; so they would give up. They often lacked persistence and confidence when solving problems that they had the resources (ability) to solve.

A similar observation was made by Resnick[8]:

> "[T]he reconceptualization of thinking and learning that is emerging from the body of recent work on the nature of cognition suggests that becoming a good mathematical problem solver -- becoming a good thinker in any domain -- may be as much a matter of acquiring the habits and dispositions of interpretation and sense-making as of acquiring any particular set of skills, strategies, or knowledge. If this is so, we may do well to conceive of mathematics education less as an instructional process (in the traditional sense of teaching specific, well defined skills or items of knowledge), than as a socialization process."

Research on problem solving outside the undergraduate education level has led to similar observations. Carlson compared the problem solving skills and strategies of successful graduate student problem solvers to undergraduate students. She found that the graduate students exhibited "an expectation that they would eventually solve each of these problems, *with their persistence frequently being the critical factor contributing to the solution attainment*" [9] (emphasis mine). This observation suggests that the absence of persistence will likely lead to the discontinuation of study in a particular field[9]. Another interesting study on problem solving endurance was conducted on 5th grade student by Montarello and Martens[10]. They observed that interspersing easier problems into tasks composed of difficult (unpleasant) problems improved the performance for 75% of the students.

To summarize the previous observations: our beliefs and attitudes can have a significant impact when we are trying to solve a specific problem. Of particular interest is our belief about whether or not we can actually solve the problem and our belief about the effort required to solve the problem. Probably the most significant source of beliefs about problem solving possessed by the undergraduate in chemical engineering is from their previous courses and classrooms. Unfortunately, these previous experiences often fail to develop the persistence required for the longer problems faced in upper level undergraduate engineering courses. For example, Schoenfeld[11] administered a questionnaire in twelve high school mathematics classes in grades 9 through 12, which read as follows: "If you understand the material, how long should it take to answer a typical homework problem? What is a reasonable amount of time to work on a problem before you know it's impossible?" Means for the two parts of the question were 2.2 minutes (n=221) and 11.7 minutes (n = 227), respectively. Clearly, by the time students reach upper-level engineering courses, their expectation for the time required to solve a typical homework problem has increased, but my experience from teaching Calculus I to 100's of engineering students is that the increase is, unfortunately, small. Students with the belief that problems should be solved in 15 minutes or less will give up working on a problem after a few minutes of unsuccessful attempts, even though they might have solved it had they persevered[7].

Another source of beliefs about problem solving is from our cultural background. Studies indicate that people in the U.S. are much more likely than the Japanese to believe that innate ability (as opposed to effort) underlies children's success in mathematics[12]. Schoenfeld made two important observations based on the results of these studies[7].

> "First, parents and students who believe 'either you have it or you don't' are much less likely to encourage students to work hard on mathematics than those who believe 'you can do it if you try.' Second, our nation's textbooks reflect our uniformly low expectations of students: 'U.S. elementary textbooks introduce large numbers at a slower pace than do Japanese, Chinese, or Soviet textbooks, and delay the introduction of regrouping in addition and subtraction considerably longer than do books in other countries' [12]. Regarding what is desirable, the studies indicate that -- despite the international comparison studies -- parents in the U.S. believe that reading, not mathematics, needs more emphasis in the curriculum."

And finally, in Japan and China, understanding is conceived of as a more gradual process, where the more one struggles the more one comes to understand. Perhaps for this reason, one sees teachers in Japan and China pose more difficult problems, sometimes so difficult that the children will probably not be able to solve them within a single class period[12].

Of course there are many other factors that affect persistence in problem solving beyond just culture differences, and tools have been developed to help assess those differences. For example, problem solving confidence and avoidance of difficult problems are important factors, and these can be measured using Heppner's Problem Solving Inventory (PSI)[13]. Some student are more tolerant of ambiguity than others[14], and overall anxiety and the ability to identify and recall key ideas are some of the important problem solving factors that are commonly measured using the Leaning and Study Strategies Inventory (LASSI)[15].

Within Engineering in general and Chemical Engineering in particular, there has been significant research on improving the problem solving abilities of students[16, 17] and problem solving assessment[18, 19]. Wankat and Oreovicz, in particular, characterized expert problem solvers as having a "Can-do if persist, confident" attitude and novice problem solvers possessing a "Try once and then give up, anxious" attitude[17]. Further, Jonassen et al. examined the differences between workplace engineering problems (ill-structured and complex) and classroom engineering problems, and their observations show that persistence to overcome unanticipated problems may be an even more important skill for engineers beyond the classroom[20].

In summary, there is much more to problem solving than just having the necessary facts, skills, and heuristics. Of particular importance is the belief that you can solve the problem even if it is not quickly obvious how to solve the problem, and you must possess the persistence to continue working on a problem even when early attempts are not successful. The question that we now turn our attention to is the impact of persistence on problem solving in Chemical Engineering courses. Are students that work longer on a problem, in terms of either the total time or the length of individual time blocks, more successful?

Persistence in Chemical Engineering

During the spring semester of 2009, I asked the 29 students in the Mass Transfer Operations course to voluntarily indicate in the margin of their homework the exact times they started and stopped working on their homework problems. Most of the students in this class were in their third year of college. Next, during the fall semester of 2009, I asked 60 students in our second-year Elementary Principles (i.e., material balances) course to do the same thing. By entering these times/dates into a spreadsheet, I could calculate the total time a student worked on a problem and the lengths of the individual time blocks that they used to work on a problem. Both courses included 10 homework sets with 3 or 4 problems each for a total of 30-40 problems during the semester. The homework was due roughly once per week. Every effort was made to not pressure the students into including the time they worked on each problem in the margin. On this voluntary basis, the data was provided on 173 homework sets (out of 290 possible) during the Mass Transfer class for a 60% response rate, and data was provided on 152 homework sets (out of 600 possible) for a 25% response rate in the Elementary Principles course. A secondary incentive for collecting this data is that it could be used to predict the total effort typically required when assigning homework in the future.

Mass Transfer Course

Since the first set of data collected was from the upper-level Mass Transfer course, that data is examined first. Figure 1 shows a histogram of the total time utilized on average by students for each problem in the Mass Transfer course. The typical students spent 1-1.5 hours on each problem in the course with the average being 77 minutes (standard deviation of 27 minutes). There is a valid concern that students could have inflated (exaggerated) the time utilized to complete the homework in the hope of getting the length of future assignments reduced. This was minimized by asking the students to only include the exact time they started and stopped each problem, even if they started and stopped multiple times during a given problem. One piece of evidence to support the relative accuracy of the utilization times reported is the overall consistency of the results. Only three students could be considered outliers, utilizing more than 105 minutes on average.

The next question to ask is whether or not the students that spent more time on each problem, on average, had more success in solving the problem. Each of the 34 assigned problems was graded on a three point scale with 3 points = correct solution, 2 points = correct approach but incorrect solution, 1 point = incorrect approach, and 0 points = no attempt. Figure 2 shows the average total time utilized for a single problem versus the total number of homework points received. The correlation between time per problem, which is related to persistence, and problem solving performance is weak (and certainly nonlinear despite the linear fit of the data – for example, the fit should not be extrapolated to zero time per problem), but there is some improvement in problem solving performance with the time spent per problem. If a student spends five more minute on each problem on average, they gain roughly 1% on their final homework grade. It is not clear if this information would impact the time students dedicate to solving their homework problems.

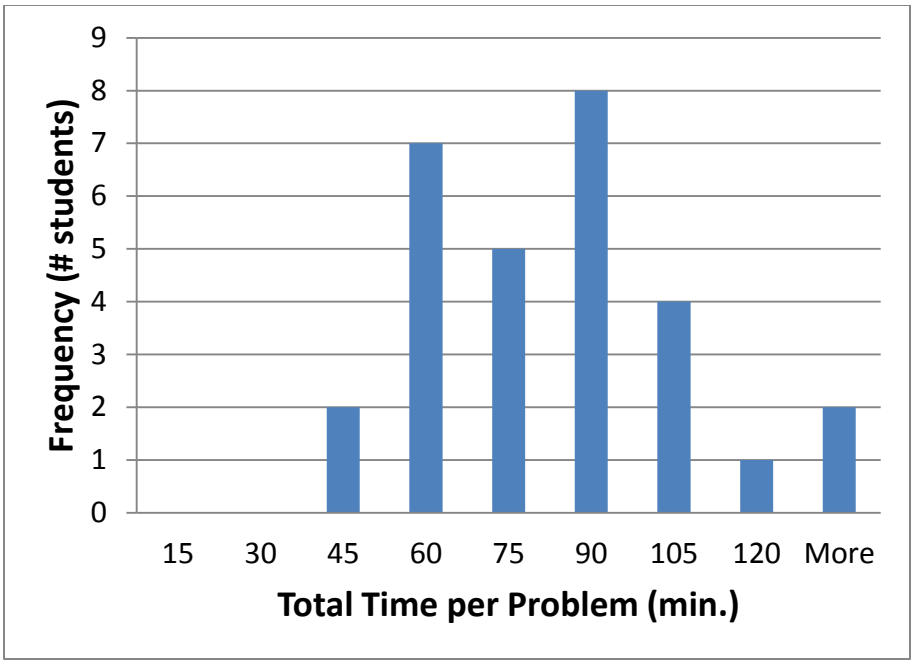

Figure 1. Histogram showing the average total time per problem utilized by students during the semester (34 total problems, 29 students, 173 reported times). No students utilized more than 155 minutes per problem on average.

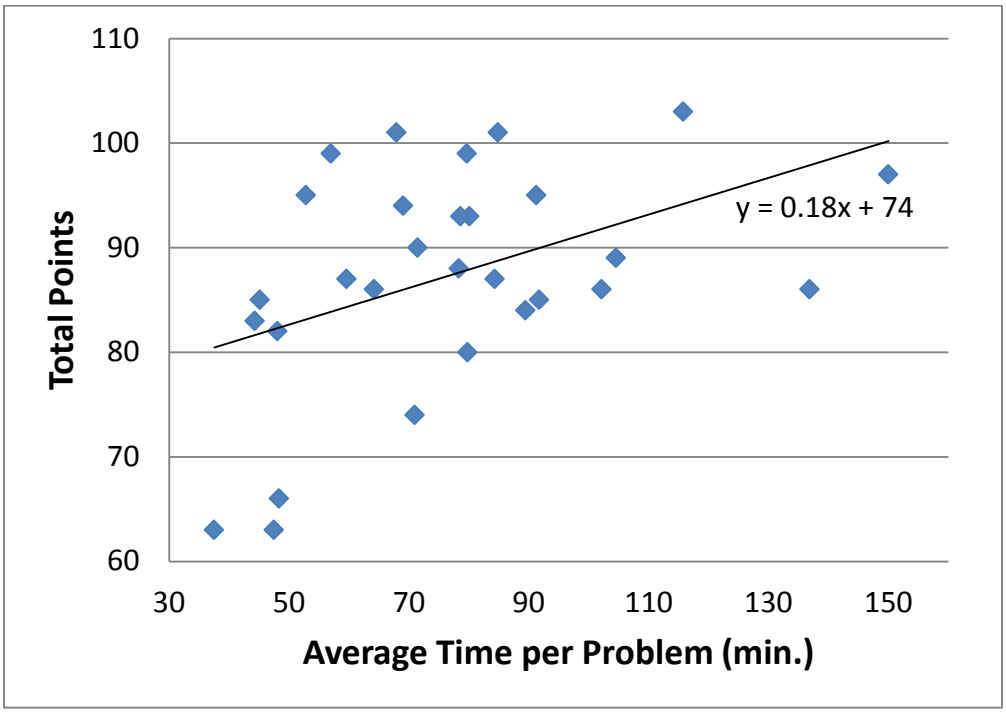

Figure 2. Correlation between the average total time utilized to solve a problem and the total points received during the semester for an upper-level Mass Transfer Operations course. There is a weak correlation between longer utilization time and improved problem solving performance.

The final question examined here is whether or not the average length of the blocks of time spent by the students on their homework problems impacted their problem solving performance. We might call each block of time a session, and a student could potentially use one session to solve all the problems or, at the other extreme, multiple sessions to solve a single problem. In this particular class, many of the students reported that they would dedicate a single, continuous block of time to each problem. Once that problem was complete they would take a break before beginning the next problem. As a result, the problem solving performance as a function of the length of a session is similar to problem solving performance as a function of the length of time spent on each problem. As shown in Figure 3, there is a weak correlation between the time per session (i.e., the average time block length) and problem solving performance. In this case, an increase of 12 minutes per session is needed to increase the final homework grade by 1%.

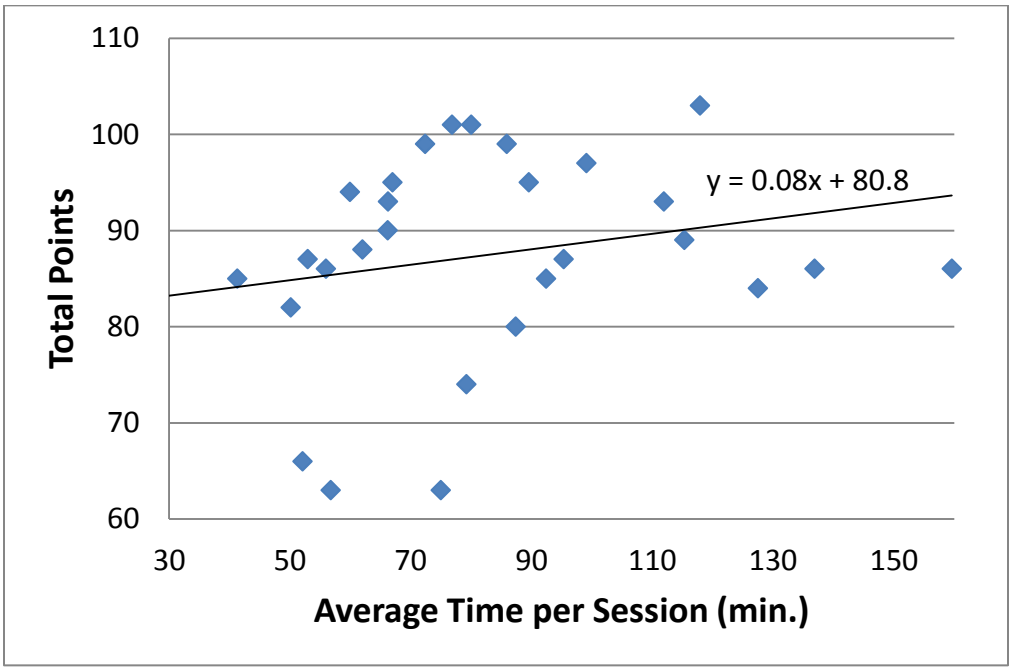

Figure 3. Correlation between the average session times utilized while solving a problem and the total points received during the semester for an upper-level Mass Transfer Operations course. There is almost no correlation between longer sessions (i.e., greater persistence) and improved problem solving performance.

The results in Figures 2 and 3 can be compared with greater statistical rigor by comparing the p-values associated with the slope of linear regression curves. The p-value, in this case, is the probability that the observed slope could be explained by random chance. A small p-value indicates, roughly, that the slope term is important to explaining the data. In our case, a small p-value would indicate the total time spent on the problem or the average length of a problem solving session is related to the final homework grade. The p-value for the time per problem curve is 0.016, which would generally be considered significant since $p < 0.05$. However, the p-value for the time per session is 0.23, which would generally be considered insignificant.

Elementary Principles Course

This course used the same grading scheme, instructor, and homework format as the upper-level Mass Transfer Operations course. Each homework problem was graded out of 3 points and 3 to 5 problems were assigned outside of class each week. Finally, both one-semester courses had a total of 10 homework assignments. For the lower-level Elementary Principles course, the time spent per problem is less than the upper-level mass transfer course, but it is still 45 minutes per problem, which is probably longer than any previous course that the student has taken. Figure 4 shows the correlation between time per problem and the total number of points the student receives. As before, there is a weak correlation showing that an additional 7 minutes per problem is required for each additional point.

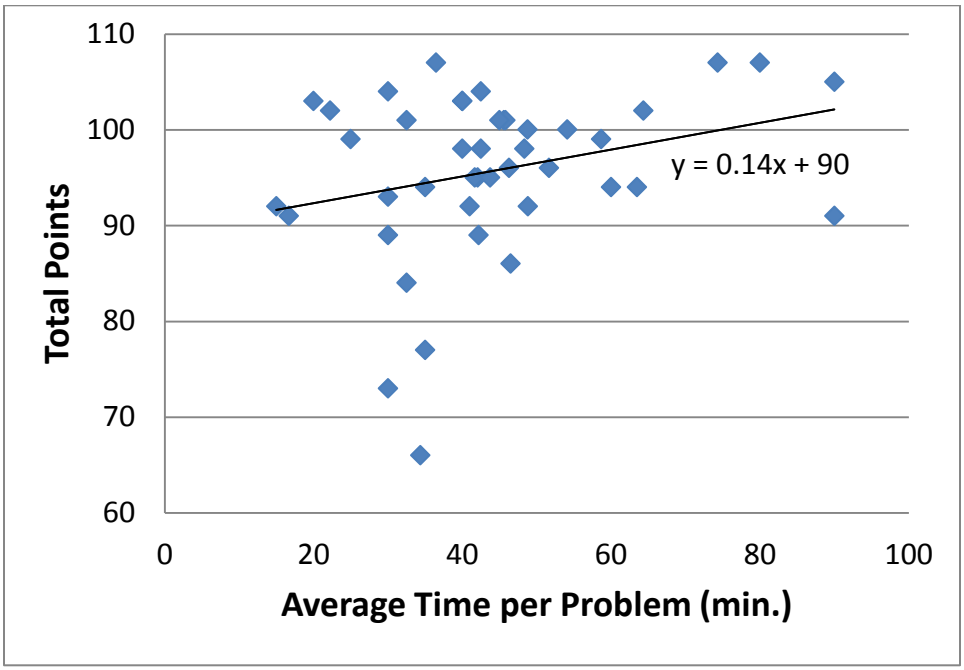

Figure 4. Correlation between the average total time utilized to solve a problem and the total points received during the semester for a lower-level Elementary Principles course. There is a weak correlation between longer utilization time and improved problem solving performance.

The time per problem solving session was more variable in this lower-level course than the upper level course. In the upper-level course, students tended to focus on one problem for approximately one hour, and then they would take a break. In the lower-level course, some student took breaks in the middle of solving a problem, and other students dedicated significant blocks of time (2-3 hours) to solving multiple problems without a significant interruption. The impact of time per problem solving session is shown in Figure 5. In this case, there is a weak, but real, correlation between problem solving session length and the total homework points received. Once again, more statistically detailed information can be obtained by comparing the p-values of the slopes for the linear regression curve. For Figure 4, the linear regression has a p-value of 0.075 indicating that the time per problem is probably a random (unnecessary) variable. The linear regression for the time per problem solving session curve shown in Figure 5 has a p-value of 0.0083, which indicates that this variable is necessary and statistically significant.

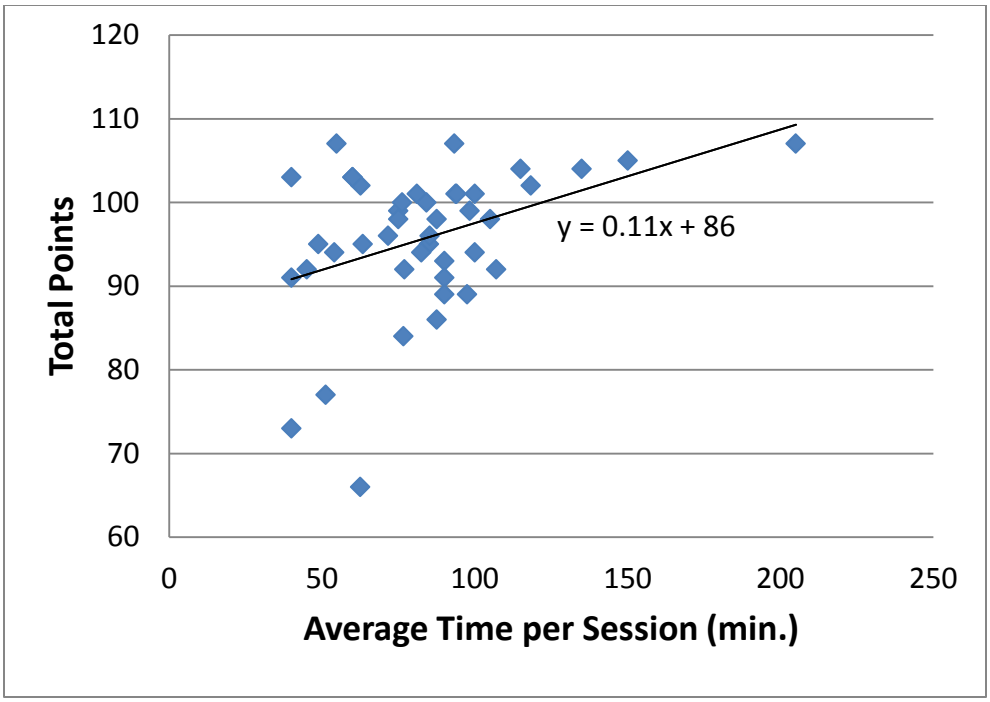

Figure 5. Correlation between the average session times utilized while solving a problem and the total points received during the semester for a lower-level Elementary Principles course. There is statistically significant correlation between longer sessions (i.e., greater persistence) and improved problem solving performance.

In summary, for the lower-level course, time per problem solving session is a significant variable in determining student problem solving success, but time spent per problem is not significant for the lower-level course. For the upper-level course, the opposite result was observed. The time spent per problem was a significant variable, but time per problem solving session was not significant.

Weaknesses

There are a number of drawbacks to this study, and the four most concerning are discussed below.

1. There are a large number of factors that determine a student's problem solving success and final homework scores in these courses. For example, the homework scores also reflect knowledge of the subject, mathematical accuracy, and help from peers. Other factors from the study environment to the attitude of the teacher impact problem solving success, but they were not considered. The focus here is on a single factor (persistence, quantified by time) and its relationship to problem solving success. Clearly, more data is needed to make any definitive conclusions, but the data presented here suggest, at most, a weak correlation between persistence and problem solving success.
2. The overestimation/over-reporting of the time required to complete the homework is possible (and maybe even likely) because there is at least a perception that future homework could be reduced in length if past homework assignments required significant time. This concern was addressed by (a) asking the students to only write down their

starting/stopping times and dates and (b) telling them that the times reported would not impact their grades or future homework assignments. The consistency of reported times is evidence that there was not significant, isolated over-reporting.

3. The data represents only one upper-level (third year) course and one lower-level (second year) course in chemical engineering, which may be past the stage when persistence is an important factor in success. In other words, only the more persistent students succeed in first-year calculus and chemistry courses and then attempt the Elementary Principles course. As someone that has taught both first year calculus and second year Elementary Principles for multiple semesters, I believe that there is a greater level of persistence required for the Elementary Principles course, but extending this study to a first year course could generate interesting data. A study of engineering freshman in Finland showed no correlation between the average grade achieved verses average time used weakly for studying, but this was focused on total study time and not on persistence in solving individual problems[21].
4. Related to the second drawback, there is a concern that the students may be relatively homogeneous and comfortable working together at this point (especially for the third-year course), which would make it difficult to identify the importance of persistence. If two students work together on a problem, the time utilized will likely represent either an average time for each individual or the time required for the slower student. Hence, longer problem solving times that show evidence for persistence may just be time spent waiting for a peer to finish the same problem. This concern is stronger for the upper-level course than the lower-level course, which may partially explain the different results for the two courses.

Conclusions and Recommendation

There is only a weak correlation between persistence/doggedness and problem-solving performance in the upper-level chemical engineering course. This could be due to the fact that the students significantly lacking persistence have already chosen to study a different field. For the lower-level course, the correlation between persistence and problem-solving performance is also not strong, but there is a connection. Lower-level students, in particular, could benefit by working to change their expectations about the time required to solve a problem in their future classes. This could be as simple as handing out a figure like Figure 1 to first year students so that they understand the level of persistence required. Further, when a student asks what he/she can do to improve their performance on the homework, the student should be encouraged to defragment the time they spend working on problems and remove interruptions and distractions as much as possible. This defragmentation change would quite possibly be more valuable than just dedicating additional time to the homework for students in lower-level courses. Another option, also recommend to Schoenfeld, is to assign longer problems earlier in the curriculum to help with the transition to the longer problems they will need to eventually solve. Since most first year courses taken by engineering majors are outside of Engineering, Engineering departments should consider encouraging the assigning of longer problems in calculus, physics, and/or chemistry. These types of changes could improve performance and retention in Chemical Engineering, overall. Ultimately, the goal is to develop persistence and doggedness in students and a gradual transition is often easier than a sudden one.

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