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The Solve - Personalize - Integrate - Think Approach in the Process Control Classroom

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The "SPIT" (Solve – Personalize – Integrate – Think) Approach in the Process Control Classroom

Abstract

In courses with heavy reading loads, traditionally in the humanities, one approach to homework assignments carries the acronym SPIT – for Summarize, Personalize, Integrate, Thoughtful puzzle – a four-step algorithm that engages students with the reading material. First, they are charged to provide a summary of the text of specific length; next, to explain how that reading connects to their personal lives; next, to explain how the reading integrates with either the course or their overall curriculum; finally, to provide a "thoughtful puzzle," another question they could answer or problem they could tackle, based on the information from the reading.[1] The SPIT approach is meant to increase student exposure to the text and to get them to work metacognitively; that is, to think about their own thinking and learning.

The SPIT approach is an example of an implementation of Writing to Learn. WTL is a movement that has been explored primarily in the humanities and social sciences, with indications that non-traditional writing assignments can improve student attitudes toward writing, but may not always impact performance in the specific discipline[2]. Some work has also been done in engineering to show modest positive correlation between writing performance and exam performance in courses in thermodynamics and process control.[3]

With the goals of increased practice and metacognition in mind, the SPIT approach has been adapted in our university's chemical process control course to replace traditional problem sets. Rather than complete a homework set, students instead work on a single problem a week, but are charged to work with the problem in four different ways, following the same approach but replacing the "Summarize" step with "Solving" the problem. Thus, students solve the problem, connect it to their personal experiences, integrate it with their chemical engineering understanding from other courses, and finally propose a related problem that they should now also be able to solve.

Based on three years of data, student performance on these four-part assignments is correlated to student performance on traditional exams. We provide examples of some SPIT prompts as well as a discussion of how each of the four components is evaluated. We seek to determine whether student performance on one or more of these four pieces of their homework assignment is an indicator of their ability to solve typical process control problems.

Introduction

The University of Maryland Baltimore County is a medium-sized, mid-Atlantic, public institution with an undergraduate student body that is made up of 75% full-time and 25% part-time students. The overall population is 53% male and 47% female, with about 40% of students representing minority populations. Over the years 2013-2015, of the 141 students who completed the chemical engineering department's required course in chemical process control and safety, the population was 73% male and 27% female, with a demographic of 47% white, 28% Asian, 15% black, 3% Hispanic, 1% Native American, and 6% other, as self-identified using the online software CATME.[4]

Chemical Process Control and Safety is a new required course developed in the Spring of 2013 to replace a more traditional process control course, offered only in the spring semester. The prerequisites for the course are numerical methods, differential equations, thermodynamics, and fluid mechanics. It is customarily taken in the junior year, concurrently with heat and mass transfer and chemical kinetics, though it can also be taken in the senior year as it is a co-requisite to spring semester capstone design. Less than 10% of the students from 2013-2015 took the course concurrently with capstone design; the majority of students were in their junior year.

The course includes three projects, highlighting process optimization (determination of desired operating conditions), process control and tuning (illustration of a simple PID control scheme), and process safety (hazards identification for a lab and development of a Standard Operating Procedure and entry/exit protocol), which comprise of 30% of the course grade. Another 50% of the grade comes from exams and class participation. The final 20% of the grade comes from weekly homework assignments that are that are an adaption of the “SPIT paper” – each week, students are presented with a single problem or prompt and are to use the course readings and lectures, and other references as needed, to address this problem in four ways: solving the problem, connecting it to their personal life and understanding, integrating it into other chemical engineering courses or experiences, and proposing a second problem they can address with the same skills required of the original prompt.

“SPIT papers” are an assignment typically implemented in courses with significant reading loads, often in the humanities. The acronym stands for Summarize, Personalize, Integrate, Thoughtful puzzle. In this approach, students are tasked to summarize a reading assignment, then explain how the reading connects to their personal life, explain how the reading connects to another reading, course element, or curriculum, and finally describe a prompt, problem, or puzzle that can be addressed with the comprehension of the reading. This technique has been described as a form of metacognition, or “thinking about thinking,” in other words, an effort to get students to reflect on their own learning.[1]

The research question we seek to address here is whether or not the non-traditional components (Personalize, Integrate, Thoughtful Puzzle) of the weekly engineering assignments correlate with student achievement on exams in the course.

Methods

Each week, students were given a single prompt related to process optimization, control, or safety, with the same set of instructions:

Please devote a separate paragraph/section to each of the following:

- *Compose a response to the prompt by addressing the question or solving the problem and clearly explaining your approach in enough detail that no “steps” are skipped.*
- *Connect the prompt to your own life, outside of chemical engineering.*
- *Connect the prompt to your understanding of the chemical engineering discipline.*

- *Create a related prompt or problem that you can now address. Clearly explain your prompt and how it is different from the original prompt. Clearly explain the solution method for your prompt and how it is different from the original.*

The wording here reflects the 2014 and 2015 homework assignments, after several student evaluations in the Spring 2013 semester indicated an inability to take the prompts as seriously since they were referred to as “SPITs.” The content of the instructions was not changed. Example prompts for the weekly problem are provided in Appendix A.

Fourteen prompts were assigned during the semester, due at the same time each week, though students knew in advance that their four lowest submissions would be dropped from final grade calculations. Each of the four components of the assignment was weighted equally at 20% of the total grade for the week, with grammar and format accounting for the remaining 20%. The rubric used to evaluate all assignments is provided in Appendix B, and students receive this rubric at the start of the semester. For at least the first half of the semester, the course instructor met with the student graders each week to review the week’s assignment and calibrate assessment on 2-3 submissions before the rest of the assignments were evaluated.

In 2014 and 2015, there were four 50-minute midterm exams given during the semester. The first was a “prerequisites” exam covering basic differential equations, thermodynamics, and/or fluid mechanics, followed by three exams whose content was restricted to process optimization, control, and safety, respectively. In 2013, the midterm exams were combined differently so there were two 100-minute exams instead of four 50-minute exams. In all years, the two-hour final exam was cumulative. All exams were graded by the course instructor.

In 2015, a survey was given at the end of the semester to collect feedback from students regarding their attitudes in having writing assignments in the course. The questions specific to this project asked about their attitude toward the writing assignments, whether or not students believed the writing contributed to their learning, and whether or not these writing assignments should be continued in future semesters. Each of these questions were answered on a seven-point Likert scale. There was also a free-response question for comments related to writing.

Results

Because only the highest-scoring ten assignments counted toward the final grade, the plurality of students completed exactly ten assignments, with two-thirds of all students submitting either ten or eleven. In total, 1,515 homework assignments were evaluated, and the distribution is shown in Figure 1, below.

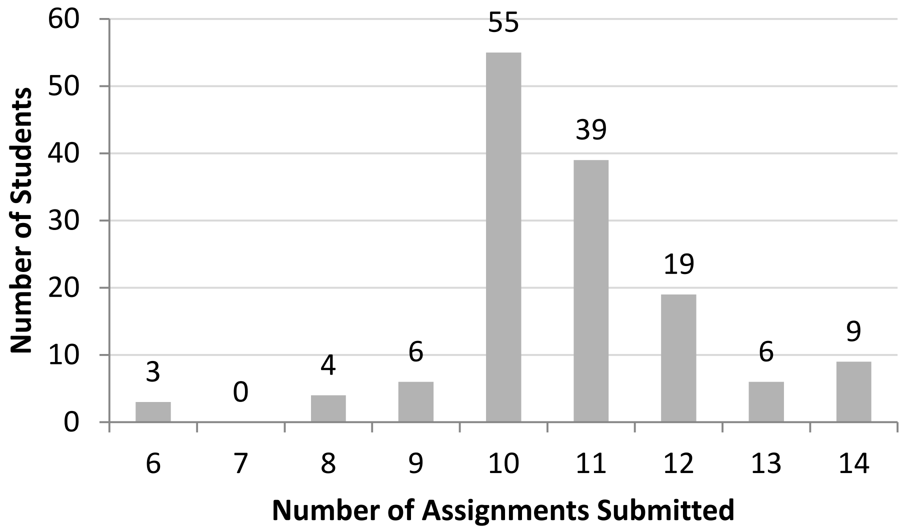

Figure 1: Counts of Student Assignment Submissions

The average exam scores by number of homework submissions is shown in Figure 2. The raw number of assignments submitted has virtually no correlation with exam performance. To determine if there is a statistically significant difference among the groups, One-Way ANOVA is conducted and it is plausible that all groups' mean performance is comparable ($p = 0.69$).

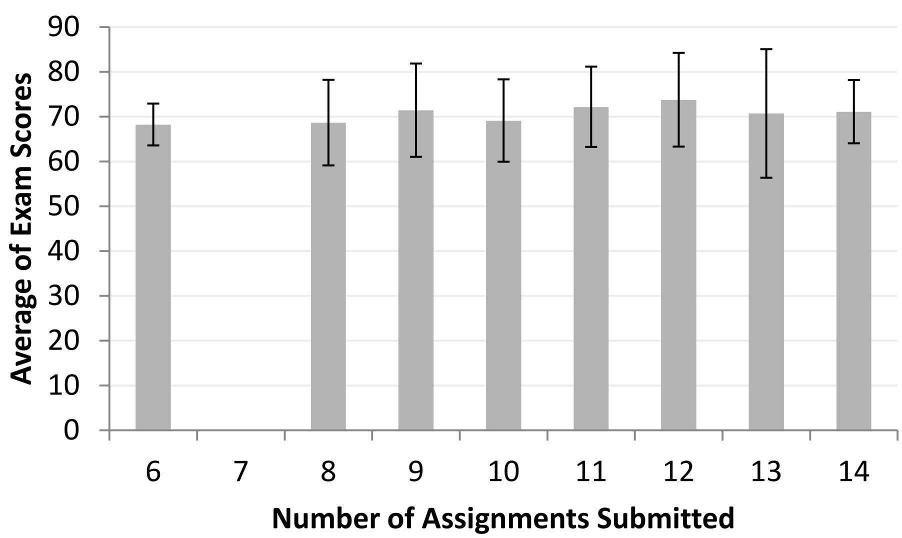

Figure 2: Exam Performance based on Homework Submissions. Error bars represent plus and minus one standard deviation.

To determine whether homework assignment performance is related to exam performance, a multiple linear regression is conducted to predict exam score as a function of performance on the five components of the homework rubric: solution, personalization, integration, thoughtful puzzle, and communication (style, usage, and layout). The form of the regression equation is given by Equation 1,

$$E = \beta_S S + \beta_P P + \beta_I I + \beta_T T + \beta_C C + \beta_0 \quad [1]$$

where *E*, *S*, *P*, *I*, *T*, and *C* are the student's average exam, (homework) solution, personalization, integration, thoughtful puzzle, and communication scores, respectively, and the β_i values are the regression coefficients for each homework rubric score with β_0 a constant intercept. Exam scores are out of 100 points, while the homework subscores are each out of 20 points.

Two such regressions are conducted: one where the average scoring in each of the five components is used, and one where the total scoring over each component is used. The former is implemented in an attempt to correlate results independent of the quantity of student submissions, while the latter more deliberately, albeit indirectly, considers number of submissions.

Table 1 lists the means, standard deviations, and probability of being nonzero (i.e., the P-value) for the six regression coefficients where average SPIT rubric scores are used as the independent variables. It can be claimed with better than 0.01 significance that the Solution, Personalization, and Integration components of the homework assignments have a nonzero correlation with the exam scores under this regression. The Personalization component has a negative correlation with exam scores, while the Integration component has a positive correlation. It appears that student performance on the Thoughtful puzzle and their attention to grammar and format do not correlate with exam performance.

Table 1: Regression Data for Average Homework Subscores

Coefficient	Mean	Standard Deviation	P-value
Solution (β_S)	2.60	0.435	2.0×10^{-8}
Personalization (β_P)	-1.66	0.632	0.0097
Integration (β_I)	1.83	0.530	0.00074
Thoughtful puzzle (β_T)	0.279	0.468	0.55
Communication (β_C)	0.341	0.574	0.55
Regression intercept (β_0)	14.0	8.24	0.091

This first regression only considers average homework subscores, regardless of the number of submissions during the semester. In an attempt to better take into consideration the quantity of submissions, the same regression is conducted for cumulative homework subscores by taking the independent variables from before and now multiplying each by the number of submissions. The results of this second regression are presented in Table 2.

Table 2: Regression Data for Cumulative Homework Subscores

Coefficient	Mean	Standard Deviation	P-value
Solution (β_S)	0.223	0.0464	3.9×10^{-6}
Personalization (β_P)	-0.117	0.0730	0.11
Integration (β_I)	0.113	0.0613	0.068
Thoughtful puzzle (β_T)	0.0206	0.0538	0.70
Communication (β_C)	-0.0829	0.0588	0.16
Regression intercept (β_0)	48.2	3.58	1.1×10^{-26}

The results here are different than those for the average homework subscores: the Solution subscore still has a significant correlation with exam scores, but the statistical significance for the Personalization and Integration scores has increased by 1-2 orders of magnitude. It can still be claimed with some significance that Integration has a positive correlation with exam performance.

The 2015 student opinion surveys were completed by 59 of the 60 students in the course. Students were asked to rate on a scale of 1 to 7 (4 being neutral, lower numbers negative, and higher numbers positive) how these writing assignments impacted their attitude toward the course, their perceived learning in the course, and how much they believed similar assignments should be given in the future. The results are given in Figures 3-5, below. The proportion of students reporting a positive attitude (ratings of 5 through 7) on the assignments is 68%, while 88% believed there was a positive impact on their learning, and 86% recommended that similar assignments be implemented in the future.

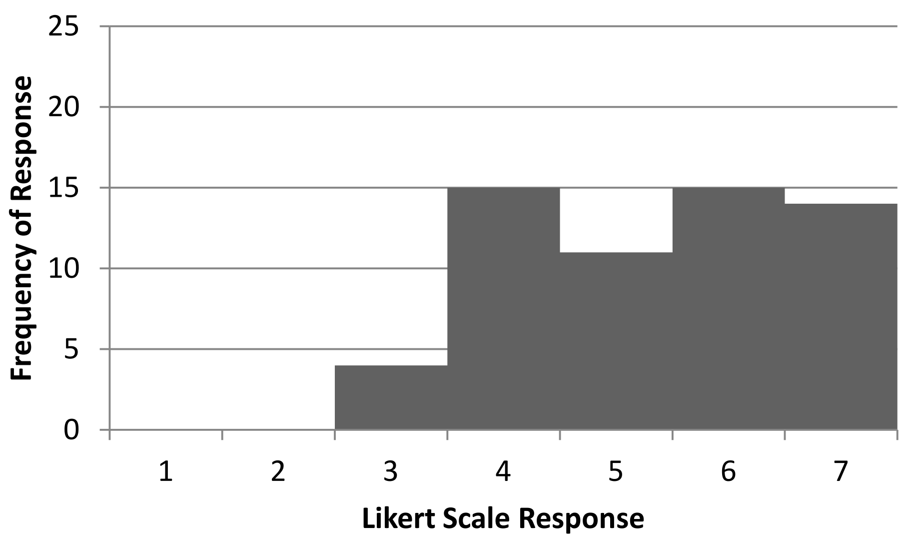

Figure 3: Self-Reported Impact of SPIT Assignments on Student Attitude toward Course (1=strongly negative; 4=neutral; 7=strongly positive).

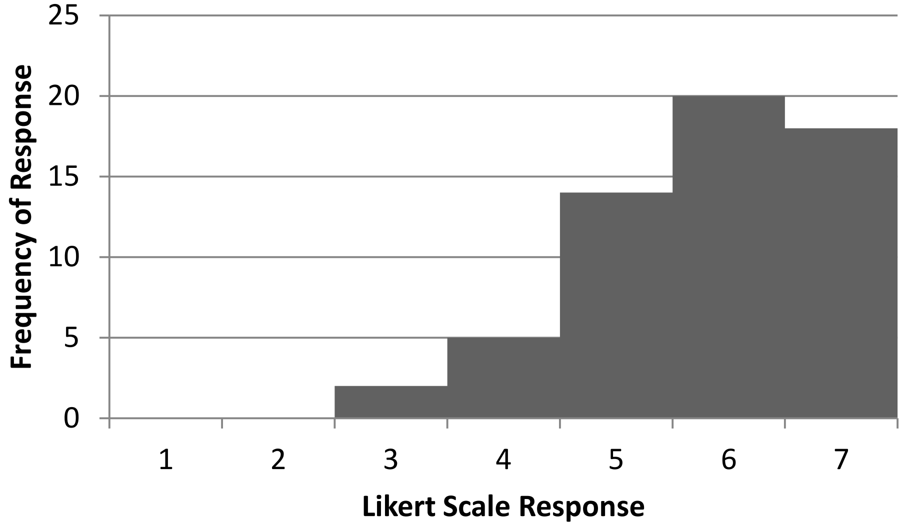

Figure 4:Self-Reported Impact of SPIT Assignments on Student Learning in Course (1=strongly negative; 4=neutral; 7=strongly positive).

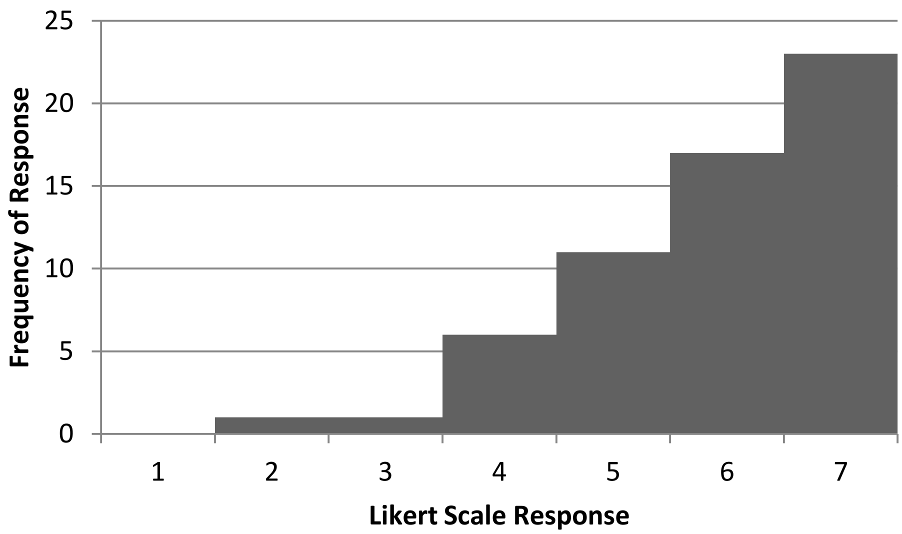

Figure 5:Student Recommendations Regarding Continuation of SPIT Assignments in Course (1=strongly disagree; 4=neutral; 7=strongly agree).

The free response portion of the survey led to comments from the students largely about the quantity of writing. The only negative responder to leave a free response comment offered that "…that the amount of writing was a little bit on the heavier side. If [there is] a way to demonstrate the same course objectives, just with less writing, I feel that we will obtain the knowledge better." The students who provided neutral ratings, and even many of those with positive ratings, offered similar opinions regarding the length or frequency of assignments.

Discussion

The most consistent statistically significant claim that can be made by the data here is that student performance on the Solution component of homework problems correlates positively with student performance on exams. This is not surprising, given that exam problems are most comparable to the original homework problems.

Of the other components of the SPIT assignment, the Integration component has the most significant impact on student performance. This is encouraging, as it suggests that a deliberate invitation to have student reflect on course content as it relates to their other chemical engineering courses or the overall profession results in improved performance. This is in general agreement with other findings in teaching and learning, which suggests reflection is a form of content practice, and the different kinds of practice improve learning.[5]

It is observed that the Personalization component on average has a negative correlation and cumulatively has no correlation with exam performance. The Thoughtful puzzle component has no correlation with exam performance whether considered on average or cumulatively. This may not mean that these components of the homework assignment do not have merit; for example, they may promote other important goals of significant learning,[6] but these data suggest that they do not improve student ability to solve typical exam problems in this class.

Finally, there appears to be a stronger statistical significance between average homework grades and exam grades than between cumulative homework grades and exam grades. This may suggest that the quality of student submissions is more important than the quantity of them. As student enrollments continue to grow at this university, this makes a strong case for reducing the required homework and grading load for this course.

The literature suggests that connecting new content to past or personal experience promotes learning.[7] There are several possible reasons that the data presented here do not support the same conclusion. For one, traditional exams may not allow for students to demonstrate adequately their mastery of this course's content. One possible way to probe this would be to examine student performance on course projects, though this would be difficult currently since projects are team-based. Another possibility is that the homework rubric is not properly calibrated. This is by no means a validated instrument, so it is possible that the evaluation of these components of the homework needs refinement. Finally, it may be likely that student learning is manifesting itself in ways outside the scope of the course. For instance, anecdotally, some students continue to contact the course instructor with further examples of Personalization and Integration of process control assignments long after the course has ended.

It is also worth considering student opinion of these particular assignments. While no thorough collection of data has been completed, teaching evaluations and the 2015 opinion survey have included requests to require fewer SPIT assignments, to allow writing assignments to be done in groups, or to make one or more of the Personalize, Integrate, Thoughtful puzzle components optional in a given week's assignment. Some students claim that the structure of the assignment becomes repetitive, or that they find themselves "reaching" to meet a given week's invitation to connect more advanced process control to their personal lives.

There are several limitations to the analysis provided here. Because of the grading policy of the course, homework assignments were dropped, and therefore few students completed all assignments, while the rest largely chose not to complete different assignments for different reasons. In one semester it was apparent that students had several exams in other courses in the same week, so less than 25% of students completed that week's assignment. It may also be worthwhile to compare homework subscores to the exam corresponding to a specific topic (for example, process safety), but again the homework policy resulted in too few data points for some sections of the course. Therefore the average and cumulative homework subscores were used as variables in regression analysis, but more refined partitioning of the data may need to be examined. Finally, assignments and exams were not identical year to year, and the sequence of course content was altered between 2013 and 2014. The specifics of a given homework assignment, or even the sequence in which the content was treated in the course, may have had impacts on homework and/or exam performance. As a result of these limitations, this analysis makes a simple yet measureable claim, at the expense of the possibility of more sophisticated claims or observations on the data.

Conclusions

This paper presents the data from three semesters of a course on chemical process control and safety to determine whether assignments not only to solve traditional homework problems, but to also reflect in writing on how they connect to their personal lives and understanding of the chemical engineering discipline, impact exam performance. This was done by modifying what is known as a "SPIT paper" to tackle traditional homework problems.

It was found with statistical significance that student performance on the traditional solution of homework problems correlates with performance on exams. It was also found that having students write about how homework problems connected to the chemical engineering discipline had a positive correlation on exam performance. Having students write and outline solutions for related homework problems had no significant correlation on exam performance. It was also found that average quality of student homework responses lead to stronger correlations to exam performance than total quantity of homework submissions.

Based on the data, future iterations of the course should consider assigning fewer such homework treatments. The rubric used to evaluate these modified SPIT papers should be further revised. Work should also continue to find innovative ways to assess student skills with the course content.

Appendix A: Example SPIT Assignment Prompts

Note that all examples were preceded by the general SPIT instructions presented in the Methods section of this paper.

Optimization Example:

As chemical engineers, we must be stewards for the environment, so while we are always seeking to make money, we also must operate our plant so that environmental impacts are minimized. One refinery has contacted our agency to ask for help in processing their hazardous wastes.

The refinery develops their main product P from two raw materials X and Y. One ton of X and 2.5 tons of Y are required to process 1 ton of P, with 1 tons of hazardous waste W (and 1.5 tons of non-hazardous wastes) as a byproduct. There are three options for treating this waste:

- React one additional ton of X with one ton of W to produce a secondary product P_2.
- React one additional ton of Y with one ton of W to produce another product P_3.
- Treat the waste directly so that it is permissible to discharge it to the environment.

The products yield profits (that is, revenues minus expenses) of $2,500, negative $25, and $100 per ton for P, P_2, and P_3, respectively. (Note that this means producing P_2 actually results in a financial loss.) The direct treatment option costs $300 per ton of W. Raw materials arrive to the plant at a rate of 7,500 tons of X and 10,000 tons of Y per day. Assume all reactions run to completion.

Determine how much of each product and treated waste should be created per day to maximize refinery profits.

Process Control Example

Develop the set of dynamic equations that describe two isothermal CSTRs in series, depicted in Figure 1 on the next page, using an actuator/process/sensor model approach. Assume that a single irreversible reaction A→B occurs in this system where the rate of reaction is given by $r=kC_A^2$. The feed to the first reactor is the input variable and the flow controller has a time constant of 2 seconds. Assume that the lines labeled with F's represent ***mass*** flow rates. The inlet feed is 100% A with concentration C_{A0}. The output variable is the concentration of B in the outlet stream and has an analyzer delay of 5 minutes. Assume perfect level control (the flow rate out of the reactor is the same as the flow rate into the reactor).

Then use MATLAB to simulate the **start up** of this reactor system (actuator, process, and sensor) by numerically solving the system of differential equations using the additional values below. For the *process*, write the two material balances each on A and B (in each unit). For the *sensor*, just focus on the analyzer.

time constant for flow control loop on feed stream: $\tau_v = 2$ s
specified mass flow rate to reactor: $F_{spec} = 0.9$ kg/s
volume of each reactor: $V_{rxtor} = 10$ L
feed concentration to process: $C_{A0} = 1.0$ gmol/L
density of all streams: $\rho = 0.96$ kg/L
rate constant for reaction: $k = 0.04$ L/gmol·s
deadtime for analyzer to measure C_A exiting second reactor: $\theta_A = 300$ s

Explain the implications of the time it takes the reactors to reach steady state as it compares to the deadtime of the analyzer.

Process Safety Example

In the laboratory, it is important that cylinders of compressed gas are securely anchored so as to be immovable. If a pressurized cylinder were to fall over, it's quite likely that the valve would shear off, effectively turning the storage tank into a considerable projectile (you can probably pretty easily perform an internet search to see photos of holes blown in walls from this kind of accident).

Assume a cylinder contains nitrogen pressurized to 2,000 psia. If the valve were to shear off, it would leave behind a hole of inner diameter 0.5 inches. Clearly state all assumptions to justify the use of specific values and equations in Crowl and Louvar, or otherwise start with conservation of mass, energy, and momentum, and numerically determine the maximum force (in lb_f) with which the cylinder would be propelled in this scenario.

Appendix B: SPIT Assignment Rubric

Criterion	Proportion of Earnings	Characteristics of a very good response (80-100% of possible points)	Characteristics of an acceptable response (50-70% of possible points)	Characteristics of a poor response (20-40% of possible points)
Response to original prompt	20%	All parts of prompt are addressed and all technical content is complete and accurate, with perhaps some minor error in transcription or computation.	Most to all parts of prompt are addressed. Several minor errors or one significant technical error.	Some to all parts of prompt are addressed. More than one significant technical errors.
Connection to life outside chemical engineering	20%	Connection between prompt and application to personal life outside of course is clearly considered, showing evidence of serious thought and effort.	Connection between prompt and application to personal life outside of course is mostly clearly considered or somewhat trivial.	Connection between prompt and application to personal life outside of course is unclear, not well discussed, and/or trivial.
Connection to chemical engineering discipline	20%	Connection between prompt and application to chemical engineering knowledge is clearly considered, showing evidence of serious thought and effort.	Connection between prompt and application to chemical engineering knowledge is mostly clearly considered or somewhat trivial.	Connection between prompt and application to chemical engineering knowledge is unclear, not well discussed, and/or trivial.
Creation and discussion of related prompt	20%	Proposed prompt or problem is clearly related to the original prompt, includes an accurate discussion of the solution or solution method, displays further understanding of the course material.	Proposed prompt or problem is missing one of the three qualities expressed at left: clear relation to original prompt, accurate solution discussion, display of understanding.	Proposed prompt or problem is missing two of the three qualities expressed at left: clear relation to original prompt, accurate solution discussion, display of understanding.
General communication, format, and style	20%	Memo is properly formatted in terms of font, layout, captioning, and length, uses correct, clear, and appropriate technical English, is professional in tone and has few to no typographical errors.	Some errors in formatting, usage, and grammar – enough to be distracting while reading.	Several errors in formatting, usage, and grammar – enough to be confusing to read and understand.

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