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Integrating Problem-Solving Studio into 75-minute Chemical Reaction Kinetics Sessions

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Integrating Problem-Solving Studio into 75-minute Chemical Reaction Kinetics Sessions

In Fall 2021, I started teaching 75-minute Chemical Reaction Kinetics Sessions. By the end of the Fall semester, I noticed the following challenges for me as an instructor: (1) to deliver the required contents in two 75-minute lectures per week and 15 weeks; (2) to help students climb the Bloom's taxonomy; and (3) to motivate positive teamwork. It is also hard for students to integrate the knowledge introduced through PowerPoint slides and pre-recorded videos in problem solving.

Problem-solving studio (PSS) was designed to teach students how to solve engineering problems without resorting to rote memorization of algorithms, while at the same time developing their deep understanding of the course topics. This is a core skillset that would help me address the challenges that I am facing; however, each session usually takes up to one and a half to two hours. After I attended the PSS held by Dr. Joe Le Doux, Dr. Carmen Carrion, and Dr. Sara Schley at Georgia Institute of Technology through Engineering Unleash, I decided to try to incorporate PSS into the 75-minute Chemical Reaction Kinetics Sessions by making the following adjustments: (1) I introduced Decision Trees through a 'Guess the Animal' activity. This activity served as the icebreaker activity to promote teamwork and stimulate discussion. Decision trees are important in learning Chemical Reaction Kinetics concepts. (2) I paired students and rearranged the table from a traditional lecture to a four-student interactive table. This was designed to motivate students to participate in PSS. (3) I flipped the classroom by making reading assignments and quizzes for reading assignments. The quizzes were due right before the lecture. This can help me to cover the target contents and motivate students to come to my classroom prepared, so that I can focus on the key contents that most students were struggling with. (4) I left one session for in-class activity after each chapter. I started with well defined questions and then gradually moved toward less defined questions toward the end of the semester. (5) I adjusted the pace of PSS by combining small group discussions and large group announcements. By making all these adjustments, I was able to conduct PSS in 75-minute sessions without rushing my students. I was able to promote active participation of my students from 40% (Fall 2021) to 90% (Fall 2022) and significantly increased the confidence of my students in problem-solving and the average of quizzes and exams.

1. Introduction.

The integrating effective problem-solving techniques into engineering education is essential, especially when considering critical factors such as public health, safety, and welfare, and global, cultural, social, environmental, and economic influences. Such integration is pivotal in preparing students for real-world engineering challenges. This study aims to adapt the Problem-Solving Studio (PSS) sessions into a concise 75-min format. Initially pioneered by Joseph M. Le Doux and Alisha A. Waller at the Georgia Institute of Technology in 2016, the PSS approach represented an innovative educational paradigm designed to enhance analytical problem-solving skills while deepening students' conceptual understanding of engineering principles(*1*). The unique structure of the PSS emphasizes collaborative teamwork, interactive engagement with in-class mentors and instructors, and a dynamic approach to escalating the complexity of problems. This methodology aligns well with modern educational theories that advocate for active, student-centered learning environments. My involvement in the 2022 PSS workshop at the Georgia Institute of Technology, conducted by Joseph M. Le Doux, Carmen Carrion, and Sara Schley, offered valuable and practical insights(*2*). Since then, my goal is to effectively integrate PSS into Engineering Curriculum, aiming to foster a robust problem-solving mindset among engineering students.

A challenge inherent in the PSS approach is its duration, typically spanning 60-90 minutes per session. This duration poses difficulties in integrating PSS into the structure of junior and senior Chemical Engineering Core Courses, which are typically organized into two 75-minute sessions weekly over a 15-week period. This situation has driven me to create activities specifically designed to fit the PSS format within the 75-minute session constraints effectively. The urgency to adapt PSS for shorter durations has been further amplified by recent curriculum changes. Recently, changes were made involving transitioning sophomore-level engineering courses from two 100-minute sessions to three 75-minute sessions per week, better aligning with students' learning needs and schedules.

2. Chemical Engineering Reaction Kinetics Course Structure

This course is a chemical engineering core subject for chemical engineering juniors (12 students) in their first semester, focuses on Chemical Engineering Reaction Kinetics; henceforth RK. Students are tasked with comprehending and mastering the principles and knowledge encapsulated in the first ten chapters of 'Elements of Chemical Reaction Engineering' by H. Scott Fogler, 5th ed., Prentice-Hall, Engelwood Cliffs, NJ (2016). This learning takes place across two 75-minute sessions per week, spanning a 15-week period, aiming to fulfill the student outcomes outlined in Table 1. Besides these student learning outcomes, as an instructor, there's an imperative to guide students towards achieving student outcomes 1 and 2, essential for meeting the standards of the Accreditation Board for Engineering and Technology (ABET) (*3*).

In Fall 2021, the course was delivered primarily through lectures using PowerPoint (PPT) slides, supplemented with homework, and exam. However, significant time was devoted to equation derivations and examples, which limited the coverage of the required content. This approach led to predominantly passive learning among students, who often found themselves overwhelmed by the volume of information, struggling to familiarize with, understand, or apply the core principles and knowledge. Consequently, the instructor recognized a shortfall in effectively guiding students through the higher levels of Bloom's taxonomy (*4, 5*) and in achieving the prescribed learning outcomes.

Beginning in Fall 2022, to ensure the coverage of essential content, foster active student progression from simply memorizing or becoming familiar with chemical engineering principles to creatively designing new reactors, and to encourage positive teamwork, the instructor adopted the Problem-Solving Studio (PSS) methodology in teaching. The approach enabled more extensive coverage of knowledge in the Fall 2022 semester. Students proactively reviewed the textbook and course material before class. By flipping the classroom, the instructor's role shifted to clarifying students' confusions and facilitating the active application of principles and knowledge during PSS sessions. Throughout the semester, students engaged in consistent practice of positive teamwork.

Table 1. Student learning outcomes of the Chemical Engineering Reaction Kinetics Course.

1.	Students can write and apply appropriate balance and constitutive equations for a given reactor scheme.
2.	Students can obtain a functional rate law for a given chemical reaction from experimental data for the reaction.
3.	Students can obtain an optimal design of a reactor scheme from among possible alternatives.
4.	Students can use Excel spreadsheets to obtain solutions to problems in which analytical solutions are not possible.

3. Activities for Integrating Problem-Solving Studio into 75-minute Chemical Reaction Kinetics Sessions.

3.1 Introduction to decision tree using interactive activity. Decision tree is used in organizing the principles and knowledge of RK (Fig. 1a). For instance, if the relationship between reaction rate ($-r_A$) and conversion (X) is known [$-r_A = f(X)$], one can directly evaluate the algebraic [for Continuous-stirred tank reactor (CSTR)] or integral (tubular, batch) equations either numerically or analytically to design reactor volume, processing time, or conversion; whereas, one needs to determine the relationship by combining rate law in terms of the concentration of the reacting species (e.g., $-r_A = kC_AC_B$) and the concentration as a function of conversion [e.g., $C_A = C_{A0}(1-X)$] if this relationship is unknown. Hence, it is critical for students to understand the concept and mechanisms of decision tree right at the outset of the course. To achieve this, the instructor introduced the activity 'Guess the Animal'. In this activity, an obscured image of an animal was presented to the students. They had the option to collaborate in small groups (with a maximum of three students per group) or to work individually. Each team's task was to identify the animal in the image by formulating their own questions, which could only be answered with 'Yes' or 'No'. The instructor only responded to questions from each group individually, rather than addressing the entire class. Students were encouraged to develop and expand their decision trees as comprehensively as possible (Fig. 1b). Once all the groups had successfully deduced the animal in the image, the instructor would then reveal the actual image of the animal.

3.2 Flipping the classroom. Beginning in Fall 2022, the instructor flipped classroom approach by assigning readings for each chapter, which were considered part of homework and were due before the beginning of each chapter. These reading assignments could be completed through textbook reading or by watching pre-recorded videos. The instructor did not post the PPT slides before the lecture. At the beginning of each chapter, the instructor reviewed the reading assignments to preview the content and address areas of confusion, particularly focusing on questions that a majority of students answered incorrectly. The instructor would summarize the key points of each chapter and go through the important examples during lectures, with the emphasis shifted towards application and demonstrating problem-solving skills. This approach to reading assignment freed up valuable lecture time for the PSS sessions and enabled the instructor to facilitate interactive problem-solving among students. By flipping the classroom, the instructor was able to promote active problem solving, observe and identify specific problem-solving skill gaps in students, offering more targeted coaching.

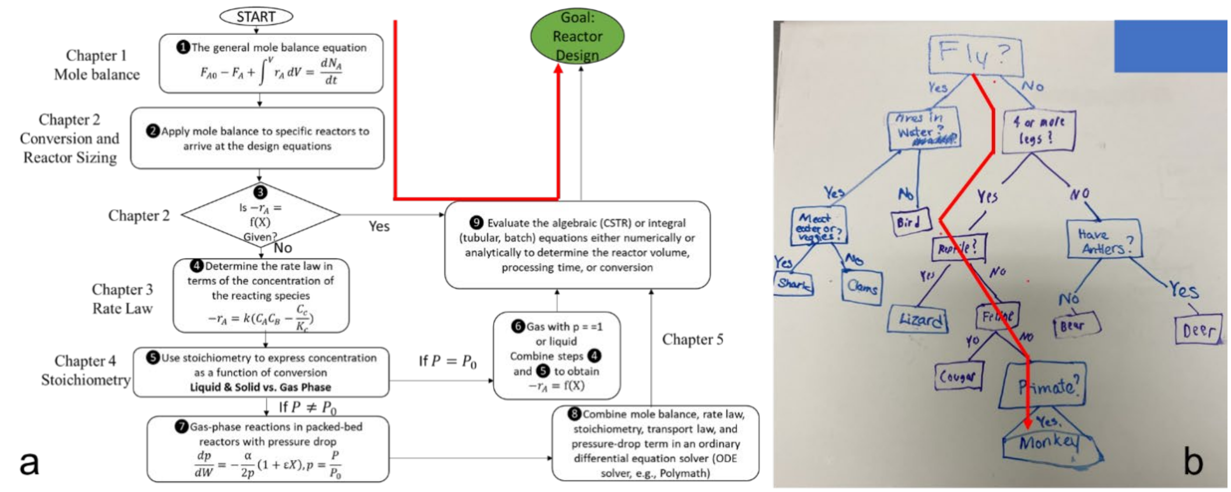

Figure 1. Interactive activity for introducing decision tree. (a) Decision tree used in organizing the principle and knowledge of RK. (b) Representative student's response of the 'Guess the Animal' activity. The represented paths for navigating the solution were highlighted in red lines in Fig 1a&b.

3.3 Problem Solving Studios. From Chapters 1-9, the instructor selected a problem for the PSS sessions that necessitated applying the key principles and knowledge from the respective chapter. After covering each chapter's content, a corresponding PSS was scheduled. Students had the choice to work individually or in groups on these problems. However, teamwork was encouraged by allowing teams to submit a single, collaborative response at the session's end, with each member's contributions clearly outlined. Students could discuss and explore how to apply the principles and knowledge addressed in the lecture to solve the problem at hand. During PSS sessions, students were free to ask the instructor questions. Rather than providing direct answers, the instructor responded with probing questions aimed at guiding students towards making connections necessary for problem-solving. If the entire class struggled with similar issues, the instructor strategically managed the pace of the PSS, deciding when and how to intervene collectively to assist the class. This approach to PSS offered several significant benefits including the following:

1. The PSS approach allows students to employ various methodologies in problem-solving, fostering creativity in their solution. Prior to PSS, there was a sense of frustration among

students when points were deducted for not using the instructor’s specific method, or when they struggled to solve problems without adhering strictly to the instructor's approach. PSS has effectively promoted diversity and flexibility in problem-solving techniques.

2. Students were encouraged to actively make connections to solve problems. Contrary to the passive approach of simply replicating the instructor's methods, as often happens in traditional lectures, students were required to actively engage with the principles and knowledge they had acquired. They needed to think critically about how to apply these concepts, connecting known and unknown variables to find solutions. This method significantly enhanced active learning.
3. Students benefitted from peer assistance and experienced a positive form of peer pressure in their learning process. Unlike traditional lectures, where students primarily rely on themselves for problem-solving, leading to a more passive learning style and less engagement with others for help, PSS facilitated a collaborative learning experience. PSS allowed students to learn from each other, often without even realizing it. There was an increase in motivation to engage in learning activities outside the classroom, driven by the desire to excel among peers. To foster this positive competitive spirit, the instructor played a crucial role in acknowledging and publicly praising individual growth and contributions.
4. Students develop positive relationships between peers and with instructor Prior to implementing PSS, there was a perception among students that the instructor was not allied with them, primarily due to the lecture-centric approach, minimal communication, and a punitive approach to mistakes in problem-solving. However, PSS transformed this dynamic, positioning the instructor as a real-time, positive support during problem-solving sessions. As students collaborated in teams to tackle problems, they built greater trust and forged more positive relationships with one another. The instructor’s role became increasingly vital in nurturing and facilitating these positive interpersonal dynamics within the classroom.
5. Students gain confidence in problem-solving after PSS. Before PSS was introduced, students often experienced long periods of stagnation when faced with challenging problems, primarily due to a lack of problem-solving skills and a reluctance to seek assistance from instructors or peers. However, PSS changed this scenario. The in-class support from the instructor, coupled with the development of communication skills and trust among students and between students and the instructor, made students more comfortable in seeking help. Successfully solving challenging problems independently or with minimal guidance enhanced their confidence, which grew progressively with each problem-solving experience. This newfound confidence encouraged them to willingly take on more complex tasks in the future.

To integrate PSS into 75-minutes sessions, the instructor did the following:

1. Adjusted the level of challenging by controlling how well-defined the problems were. The more defined a problem was, the less challenging it would be.

2. Adjusted the pace of PSS by controlling when and how to offer help to individuals or the whole class.
3. Gradually moved from well-defined problem to not-well defined problem. With the students building the problem-solving skillsets into the semester, the instructor gradually raised the level of challenge by decreasing the level of defining a problem.

3.4 Not-well-defined problem. To encourage the students to move up Bloom's taxonomy and apply their accumulated knowledge to a practical challenge, the instructor progressively transitioned from well-defined to less-defined problems (Supplementary Materials 1&2). In the final PSS session, students faced an open-ended task: "Please chose a product that you would like to manufacture and design a reactor for it." Before tackling this ill-defined problem, the instructor clarified what constitutes such a problem and the importance of learning to solve them. This preparation set the stage for 75-minutes session where students engaged in devising solutions. An evaluation of student responses to this open-ended challenge, conducted via a questionnaire (refer to Table 2), revealed a significant insight: the PSS experience had heightened students' awareness of real-world scenarios. They recognized that real-world problems often begin in an undefined state and require working backwards to find solutions. This realization underscored the practical value of the training they received through PSS.

Table 2. Summary of selected students' responses (10 out of 12 students responded).

Q1:	**What was the most important information you learned from the not-well-defined or open-ending problem-solving session?**
A1:	**Student A:** Get creative and think outside the box. **Student B:** The importance of conducting research before starting a project. **Student C:** You must establish some parameters and make some assumptions to proceed. **Student D:** These types of problems take a lot of your own personal knowledge as well as ability of applying what you've learned and takes a lot of research to achieve a solution. **Student E:** I learned how to problem solve without all the given numbers like on a test. It really gave me a good look at the real-world problems.
Q2:	**What surprised you most in the not well-defined or open-ending problem-solving session?**
A2:	**Student A:** How specific some of the examples and processes were. **Student B:** There are a lot of assumptions that must be made. **Student C:** The amount of information that we could put on the page. We also had so many resources to choose from and a lot of different routes that we could've taken. **Student D:** I never thought about how broad these types of questionnaires because I always have done in-depth problems, so it surprised me how much of your own information you need to gather. **Student E:** That some of the information took a long time to find. I always thought for reactions all the information would be relatively easy to find.
Q3:	**What action from the instructor did you find the most helpful the not well-defined or open-ending problem-solving session?**
A3:	**Student A:** The general list of reactions to look up. **Student B:** Being taught to use our thought process to create an initial layout of the problem first then obtain details to solve the problem. **Student C:** Finding the actual chemical process or synthesis to for the product.

	Student D: I like the feedback! It was nice to hear the encouragement to think differently from one another. **Student E:** I found it helpful when she provided some guide as to what the question should require because even though it's broad, it gives some push to start solving the problem. **Student F:** The instructor provided feedback while solving the problem. **Student G:** I like how my professor didn't intervene when we were struggling. She pointed us in the right direction but never gave us the numbers, we had to find those.
Q4:	**After completing the not-well-defined or open-ending problem-solving session, I believe I have a more in-depth understanding of reactor design.**
	Strongly Agree: 22.2% **Agree:** 77.8% **Neutral:** 0.0% **Disagree:** 0.0% **Strongly Disagree:** 0.0%
Q5:	**After completing the not-well-defined or open-ending problem-solving session, I have been more encouraged to make connections between reactor design concepts and applications.**
	Strongly Agree: 33.3% **Agree:** 55.6% **Neutral:** 11.1% **Disagree:** 0.0% **Strongly Disagree:** 0.0%
Q6:	**This mode of learning (open-ended problem solving) could be an effective learning strategy.**
A6:	**Strongly Agree:** 44.4% **Agree:** 33.3% **Neutral:** 22.2% **Disagree:** 0.0% **Strongly Disagree:** 0.0%

4. Conclusions

In conclusion, the implementation of the PSS within a 75-minute timeframe is feasible through strategic modifications. Adjusting the clarity and complexity of the problems presented, as well as the timing and manner of facilitating students' problem-solving processes, has proven effective. This approach has enabled the successful delivery of essential course content, actively assisted students in progressing through Bloom's taxonomy, and fostered an environment conducive to positive teamwork.

5. Acknowledgements.

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6. References.

1. J. M. L. DOUX, A. A. WALLER, The Problem Solving Studio: An Apprenticeship Environment for Aspiring Engineers. *Advances in Engineering Education*, 27 (2016).

2. C. A. Carrion, J. M. LeDoux, paper presented at the 2019 ASEE Annual Conference & Exposition, Tempa, Florida, 2019.

3. ABET. (2021), vol. 2023.
4. N. E. Adams, Bloom's taxonomy of cognitive learning objectives. *J Med Libr Assoc.* **103**, 152–153. (2015).
5. M. T. Chandio, S. M. Pandhiani, R. Iqbal, Bloom's Taxonomy: Improving Assessment and Teaching-Learning Process. *Journal of Education and Educational Development* **3**, 203-221 (2016).

Supplementary-Materials: Integrating Problem-Solving Studio into 75-minute Chemical Reaction Kinetics Sessions

Group Members: **Date:**

________________________________ CHME 3321

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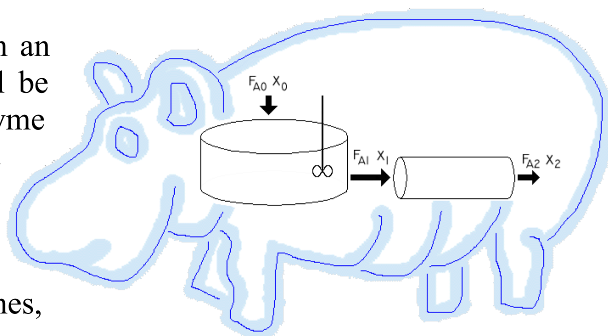
Complete the following in a group of 2-3 students, and each student should submit **ONE** packet.

Modeling the Digestive System of a Hippopotamus



For any point within the digestive system when an autocatalytic reaction is occurring a CSTR will be more efficient than a PFR, but when an enzyme catalyzed reaction occurs a PFR is more efficient than a CSTR. Hence, in the case of the hippopotamus where autocatalytic digestion occurs within the stomach, which is followed by enzyme catalyzed digestion within the intestines, a CSTR-PFR reactor scheme is desired.

The full grown hippopotamus digestive system is modeled as a CSTR and a PFR in a series. The continuous-stirred tank reactor (or the backmix reactor) is used very commonly in industrial processing and is normally run at steady state. Ideally it is operated to obtain a perfect mixing and therefore modeled as having no spatial variations in concentrations, temperature, or reaction rate throughout the vessel. The plug-flow rector is, as the CSTR, run at steady state and consists of a long cylindrical pipe. The flow is considered turbulent enough so that one can assume that there is no radial variation in concentration.

The overall conversion of all dry matter, i.e. X_2, is according to studies of the hippos digestive system about 45%. We further will assume that about 75% of the total conversion occurred in the first part of the digestive system, i.e. the CSTR or the stomach, and 25% in the second part, i.e. the PFR or the intestines [but remember overall conversion is 45%]. The volumes of the stomach (CSTR) and the intestines (PFR) are about 0.46 m^3 and 0.15 m^3 respectively. A Levenspiel plot of the stomach is shown in Figure 1 (a function of mass rather than moles), and addition Levenspiel plots of the stomach and intestines are provided in the lecture slides.

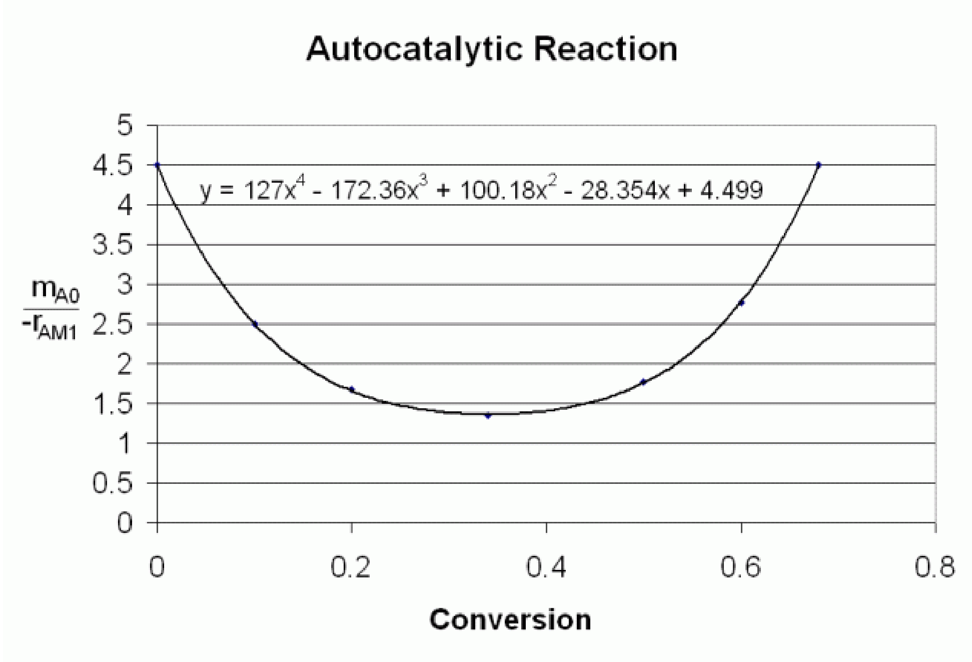


Figure 1. Levenspiel Plot for Autocatalytic Digestion in a CSTR.

1.) A hippo is full grown in 4.5 years. A baby hippo follows its mother around and eats one half of what she eats. However, the rate of digestion in the autocatalytic CSTR stomach, $-r_{AM1}$, is the same as the baby hippo as is the conversion. What is the volume of the baby hippo's stomach? (5 points)

2.) What is the conversion in the intestine (PFR) for the baby hippo discussed in Question (1) assuming that V_{max} for the PFR is one half that of the mother? (5 points)

3.) How would your answers change if the stomach (parietal blind sac, the stomach, and the glandular stomach) of the mother hippo were modeled as three equal volume CSTR's in series whose total volume was $0.46m^3$? (5 points)

4.) The mother hippo has picked up a river fungus and now the effective volume of the CSTR stomach compartment is only 0.2 m^3. The hippo needs 30% conversion from the stomach and intestines to survive. Will the hippo survive? (5 points)

5.) The mother hippo had to have surgery to remove a blockage. Unfortunately, the surgeon, Dr. No, accidentally reversed the CSTR and PFR during the operation. **Oops!!** What will be the conversion with the new digestive arrangement? Can the hippo survive? (20 points)

CHME 3321
In-class activity VI_Final

Please identify a reaction of interest and design a corresponding reactor for manufacturing or modeling this reaction. (50 pts)

<table>
<tr><th>Well-defined questions</th><th>Not well-defined questions</th></tr>
<tr><td>For example:
In-class activity VII:
1. The pyrolysis of acetaldehyde is believed to take place according to the following sequence (20 pts):
$$CH_3CHO \xrightarrow{k_1} CH_3\bullet + CHO\bullet$$
$$CH_3\bullet + CH_3CHO \xrightarrow{k_2} CH_3\bullet + CO + CH_4$$
$$CHO\bullet + CH_3CHO \xrightarrow{k_3} CH_3\bullet + 2CO + H_2$$
$$2CH_3\bullet \xrightarrow{k_4} C_2H_6$$
a) Derive the rate expression for the rate of disappearance of acetaldehyde, $-r_{Ac}$ in terms of measurable concentrations.
b) Under what conditions does it reduce to the following?
$-r_{Ac} = kC_{CH3CHO}^{3/2}$</td><td>For example:
Project II:
Please identify a reaction of interest and design a corresponding reactor for manufacturing or modeling this reaction.</td></tr>
<tr><td>Characteristics:
• With all the needed information given
• With a final correct answer
• Guide you to solve the problem step-by-step using sub questions</td><td>Characteristics:
• You need to search for the needed information
• There is no correct solution
• There are different ways to approach and solve the problem
• You need to layout a mind map to solve the problem step-by-step</td></tr>
<tr><td>Advantages:
• Apply specific piece of knowledge
• Practice the detailed problem-solving skillsets</td><td>Advantages:
• Comprehensively apply the knowledge learned on one topic
• Focus on the big picture of the problem
• Help you practice how to layout the plan/strategy for problem solving</td></tr>
</table>