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Board 25: Promoting Chemical Engineering Students' Entrepreneurial Mindset in A Chemical Reactor Design Course

Prof. Jean M. Andino Ph.D., P.E., Arizona State University

Jean M. Andino is a faculty member in Chemical Engineering and Civil, Environmental, and Sustainable Engineering at Arizona State University (ASU). She earned a Bachelor of Science degree in Engineering Sciences at Harvard University and a PhD in Chemical Engineering from the California Institute of Technology.

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Abstract

Chemical engineering students are introduced to topics in chemical kinetics, mechanisms, and reactors in traditional chemical reactor design courses. However, additional work is needed to infuse entrepreneurial mindset skills into coursework, specifically in enabling students to expand their curiosity and make connections to their everyday world. This work documents the efforts undertaken in two spring semesters (in 2021and 2023) of a required junior level Introduction to Chemical Reactor Design class at Arizona State University to enable students to (a) investigate common processes to determine the function and importance of chemical reactors, and (b) to acquire and integrate reactor design, sustainability, and consumer demand information in order to enhance the commodity production process. The factors that were explicitly assessed in this work relate to the "curiosity" and "connections" elements of entrepreneurial mindset learning, and include assessing how well students (1) investigate common processes to recognize potential opportunities, and (2) integrate and synthesize different types of knowledge. Introductory material regarding reactors was presented to the class, and opportunities to have students discuss the different reactor types that they encounter in their everyday lives was provided during a class session. Students then formed groups to carry out two homework assignments over an approximately 4-week period. The assignments consisted of a written report and also a creative presentation that focused on the use of chemical reactors in one of four different industries/sectors: food generation, pulp / paper-based products production, energy and environmental control, or pharmaceutical/therapeutics production. A quantitative rubric was developed and used to score the written reports, and student peer review was used to evaluate the creative presentations. The quantitative assessment data from the written reports show that the majority of the student teams met or exceeded expectations. Suggestions for how the project may be expanded in the future are provided.

Introduction

Arizona State University instituted a program in 2019 to infuse entrepreneurial mindset (EM) learning throughout the entire College of Engineering[1] by recruiting Robust

Entrepreneurial Mindset Leaders (REMLs). REMLs represented all different faculty ranks and worked with faculty in their individual programs to infuse EM throughout the undergraduate degree program of the major. The author of this paper was a REML in Chemical Engineering, and the work that is described documents an effort to gradually introduce students to EM in a core, required junior-level chemical engineering course: Introduction to Chemical Reactor Design.

The activities that were undertaken were focused on customer/process discovery, and were meant to expand students' knowledge regarding the use of reactors in processes that related to commonly used materials and products. The use of chemical reactors in one of four different industries/sectors: food generation, pulp/paper-based products production, energy and environmental control, or pharmaceutical/therapeutics production was explored.
The specific technical objectives were:

1. To critically investigate common processes in order to determine the function and importance of chemical reactors.
2. To investigate the parameters that would enable scale up of the chosen process.
3. To acquire and integrate different types of knowledge (e.g. reactor design, consumer or community demand information) in order to enhance the commodity production process.

Each objective was explicitly assessed through the chosen intervention.

Methods

The methods that were employed in the Reactor Design course varied based on the year. The first implementation of the activities was in 2021, during the height of the pandemic, and therefore were conducted in an online format with 49 teams, each consisting of 2 or 3 students. The second implementation was in 2023, conducted in person with 34 total teams of 2 or 3 students per team.

The initial phase of the interventions involved understanding students' knowledge about reactors and where they are used. In 2021, this was done using Jamboard and breakout rooms in Zoom. Students were randomly broken up into 4 breakout rooms and, in a 20 minute period, were asked to use the notes feature in Jamboard to list as many places /processes/products that used chemical reactors. In the 2023 in-person implementation, students formed groups of 4-8 students and had their discussions in class. A 10-15 minute report-out period followed the group brainstorming process. Students were asked to briefly describe the most interesting process that they discussed in the groups, indicate whether the process was a static or flowing process, and to think about why the mode of operation might be important or needed for their chosen process.

The creative phase of the intervention was undertaken over an approximately 4-week period of time. There were two primary assignments. Assignment #1 focused on group formation, deciding on the topic, and sharing the topic. Teams of 2 or 3 students were asked to decide – as a team- on the industry/final product or process to report on. The teams were encouraged to explore the use of chemical reactors in one of four different industries/sectors: food generation, pulp / paper-based products production, energy and environmental control, or pharmaceutical/therapeutics production, and were required to share their specific topic in a shared site in the course's learning management system (CANVAS). The public sharing of the topics was meant to allow all teams to see what other teams were investigating and to help to reduce duplication and excessive competition. Examples of potential topics were provided in each of the four categories. These included the following:

- Food Category:
  Making sauerkraut, kimchi, or chocolate
- Pulp/Paper-Based Products Category:
  Making toilet paper, writing paper, or paper towels
- Energy & Environmental Control Category:
  Making NEWater (Singapore), wastewater treatment in city X, plastic recycling/repurposing
- Pharmaceuticals/Health Products Category:
  Making aspirin

Students could also choose their own topic in the specified categories, provided that their topic involved chemical reactors.

The second assignment was the heart of the activity and was due a month after the topic was chosen and publicly shared. The second assignment had two parts: a report and a creative sharing output. Teams were instructed to engage in "customer discovery" (i.e.

research) and to use only reputable sources. For the purposes of this assignment, “reputable sources” included peer-reviewed journal papers (found through, for example, the SCOPUS database that is available through the library at Arizona State University), government web sites, or direct company information. Students were explicitly warned to not use documentaries (e.g. “How its Made”) or web sites other than the approved ones as references. In the 2021 offering of the class, a special office hour time was devoted to showing students how to search using an online database such as SCOPUS, how to gather papers into a reference management database program (e.g. Endnote® or the freely available Zotero®), and to automatically incorporate the references into documents through the reference management software so that references would be automatically formatted in their written document. Students were further instructed that the background research should enable the team to (1) describe the process that is used to create the final product, (2) explicitly identify at least one of the chemical reactions that takes place in the creation of the final product, (3) identify the type(s) of reactor(s) that is(are) used in the process, and (4) identify the demand for the product <u>in a quantitative way</u>. All four of these items had to be properly referenced in the written document. Students were able to earn bonus points by considering (a) variations to the process – specifically to the reactions and reactors- to identify future opportunities for expansion, e.g. to add new products, or (b) variations to the process to enhance the sustainability of the process. These bonus aspects had to be original ideas/methods that the team devised.

Two deliverables were required: a short (4 page, single spaced, Times New Roman 12 point font, 1inch margin) paper and a presentation or some other type of dissemination tool that described the process to the class. For the presentation or dissemination tool, students were encouraged to use their creativity. As initial ideas, students were told to consider options like creating a self-running PowerPoint presentation or using a movie maker program to develop a short movie trailer. How to convey the information was completely the choice of each team, and they were not limited to the two examples given. The teams were encouraged to be creative so that they could stand out and also have fun in creating the dissemination product. The only constraint was that the presentation/dissemination tool should be one that could be viewed within a 2- to 4-minute timeframe without intervention of the team to start the presentation since the files would be uploaded to a common site (a Google Drive) where the class could view all presentations. Multiple viewing periods for the presentations/ dissemination tool(s) were established. During the viewing periods, the class voted for nominees for the unique awards that were presented. Students were specifically asked to evaluate the presentations based on the rubric that is in Table 2. Final decisions on the awards were made jointly by the instructor and the teaching assistant. The awards that were presented included (1) the ***Highest Catalytic Effect*** award, granted to the team that most effectively enabled classmates to overcome the barrier to understanding the real-world applications of chemical reactors, (2) the ***#1 in Innovation*** award, granted to the team that provided the most innovative and engaging presentation of their real-world application of chemical reactors, and (3) the ***Best Reaction Engineering*** award, granted to the team that elicited the most reaction from viewers of their presentation on the use of reactors in a real-world process. While the first award was focused on the technical explanation, the second and third awards were meant to encourage and reward creativity and enhance students' professional presentation skills. Each of the awards was presented as an electronic certificate.

Preliminary guidelines regarding effective presentations were provided in writing to students. Specifically, students were told that effective presentations/dissemination tools would be ones that (a) clearly described the process and connection to reactors, (b) presented the chemistry, and (c) were engaging. No further guidelines were provided prior to submission.

A rubric, shown in Table 1, was used by the instructor to grade the papers. Peer student review was used to assess the presentations. In the first implementation of the activities in 2021 (during the tail end of the COVID pandemic), the reviewing of presentations and the peer review scoring process was accomplished online via Zoom, during two 75-minute class periods, and using multiple breakout groups consisting of 2 to 4 teams (a total of 8-10 students in each breakout group). Breakout groups were assigned before the class periods to ensure that no team reviewed their own presentation. Each group reviewed 6 to 8 presentations, and had the opportunity to briefly discuss the work and provide a rating of highly recommend, recommend, or missing elements by considering the rubric available in Table 2. The second Zoom-based class period was devoted to announcing the awardees, viewing presentations, and discussing the processes themselves as well as the features that made the presentations stand out.

In the second implementation of the activities in 2023, class time was not devoted to the review process. Instead, individual teams were encouraged to meet in person, review the

6-8 presentations that they were assigned, and provide a numerical score through a Google sheet that was based on the rubric of Table 3, and presented as a Likert scale ranging from 5 (best) down to 1. The criteria for the extreme ratings are provided in Table 3. Teams submitted scores as a team, and three teams were assigned to review each presentation. Thus, in 2023, the teams did not come together to review a presentation at the same time. However, a single in-person class period was devoted to announcing the awardees, viewing presentations, and discussing the processes themselves as well as the features that made the presentations stand out.

Results and Discussion

Initial Intervention: Students who participated in the online version of the activity to discuss the processes and places where reactors might be or are implemented were found to be highly engaged in discussing topics with each other and actively populating the jamboard site. Although some of the responses that were provided did not fall into the theme of chemical reactors, students were able to discuss their answers and, in general, seemed to be quite receptive to the opportunity to engage in some type of hands-on activity with the use of Jamboard. An example of the Jamboard output from one of the 2021 groups is provided in Figure 1.

In 2023, the initial intervention was done in class. Again, the students were highly engaged and eager to share and discuss their processes. No written output was gathered. Instead, this activity was used as a type of “icebreaker” activity.

Although the two interventions were successful in having students meet and speak to each other, the act of writing something down as a group seemed to spark more debate and interaction. Thus a future Spring 2024 implementation of this initial intervention is planned to include some type of written output.

Creative Intervention: The creative intervention consisted of the paper and the dissemination tool. The papers were, for the most part, exceptionally well prepared. In both 2021 and 2023 the average scores suggested high proficiency in describing their chosen systems. In 2021, some students opted to describe the work taking place in the research group that they were working in, thereby describing lab-scale systems or products, rather than commercial systems or products. Thus, in the 2023 implementation, extra emphasis was placed on the consumer demand aspect of the last criterion of Table 1. In this manner, students were encouraged to consider commercial processes.

The largest benefit of the written portion of the activity was not only in discovering information about a process that used reactors, but, instead, a more fundamental aspect related to doing research, i.e. searching for and documenting references. Most students in the 2021 offering of the Reactor Design class had not previously used a reference management software program like Endnote® or Zotero®, and if they had, they were not aware of the plugins for a program like Microsoft Word that could help them to easily insert citations and a reference section (with properly formatted references) into the paper. This aspect was particularly appealing to students since they often spent a great deal of time re-formatting references for the multiple reports that were routinely assigned for their other required chemical engineering classes. The introduction of reference management program was such a helpful activity in 2021 that in 2023, a small amount of time (10-15 mins) was spent in class to introduce all students in the class to the use of the freely available Zotero® software. As a result, the reference sections of all papers were well formatted and included peer-reviewed journal publications that could be easily downloaded into the chosen program (e.g. Zotero®, Endnote) and easily inserted into their word processing software. Website references could be added to reference management programs like Zotero® or Endnote®, but this would require a manual input. Thus, the use of a reference management program encouraged students to look for more reputable resources that had DOIs or could be downloaded into an RIS file for easy import to a program like Zotero® or Endnote®. Thus, this modification of introducing students to the use of a reference management program helped to improve the students' writing output.

The creative presentations took many forms, including movie trailers, recorded videos with demonstrations, skits or rap songs that students wrote themselves, and, of course, traditional voiceover PowerPoint videos. In 2021, student groups struggled with how to evaluate the presentations, as there were many in the "highly recommend" category. Thus, students modified the review process into a rank order to come up with their most highly recommended. Because these rankings were used to provide awards and the students had a difficult time, each group had the opportunity to suggest a "highly recommend" team for an award. Thus, in 2021, multiple versions of the three main awards were handed out. Since the awards were electronic certificates, having more than one of the same award was a straightforward process. In 2023, a numerically-based process was used (based on the rubric in Table 3) that resulted again in multiple highly recommended teams, with the highest scores being 20. However, the scoring process enabled the instructor and the TA to narrow down the award winners to just three total awards, one in each category. An example of one of the awards that was handed out appears in Figure 2. Students were quite pleased with their awards, with some adding their awards to their resumes.

Impacts and Future Opportunities

This paper suggests an approach that enables students to explore real-world uses of chemical reactor systems. Because the Chemical Reactor Design course is a math intensive, challenging course for students because it is one of the first chemical engineering courses where students must bring together multiple fields of fundamental science and engineering concepts, an alternative approach was undertaken to spark creativity. Although class periods were devoted to some of the activities, the time that was spent was helpful in further developing student skills, not just for the Reactor Design class but for other classes.

Future implementations of the activities should are suggested to include approaches that will enable a clearer assessment of how students are making connections between concepts. This could be accomplished by having students create concept maps that are tied to the three Cs of the EM framework as well as to the real-world systems that the students are studying. Even though the rubrics that were created (see Tables 1-3) are indictors that relate to the EM framework in different ways, using graded concept maps may enable a more direct assessment of students' understanding and application of the EM framework in a manner similar to other work[2–4].

References

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Table 1: Assessment Rubrics: Written Document				
Criteria	Ratings			
Overall Process Description: This indicator focuses on the investigation of common processes to recognize potential opportunities. This indicator is used to assess how well students describe their process that is used to create the overall product.	**20 pts** **Exceptionally Proficient** The team has provided an exceptionally clear indication of the overall process, including how, where and why the specific reactors are used in the process. The final product is clearly described, and the overall steps for achieving the final product are articulated. The section is properly referenced (with reputable references), and written using clear scientific language. Schematics and figures, if used, are appropriately referenced.	**16 pts** **Proficient** The information meets the guidelines for the assignment. The team has provided an indication of the overall process, including the types of reactors that are used, and the final product is described.	**8 pts** **Below Proficient** The team attempted to describe the process, but the discussion was deficient in one or more aspects. As examples, the discussion was too general in nature OR did not provide specifics on the final product and intermediate steps OR did not clearly tie the reactors to a specific step in the process, OR contained minimal or no references.	**0 pts** **No Marks/Not Addressed**
Chemical Reactions: This indicator is used to assess how well students describe the chemical reactions that are involved in the creation of the overall product.	**10 pts** **Exceptionally Proficient** The chemical names and uses of the chemicals were described, and explicit reactions were shown for all of the major steps that were described in the process. The connection to the process was explicitly stated.	**8 pts** **Proficient** The basic guidelines for the background section were met in that the chemical names and uses of the chemicals were described. However, a specific reaction was not written OR only one of the explicit reactions that was outlined in the process was provided OR the connection to the process was not fully clear.	**4 pts** **Below Proficient** The team attempted to describe the chemicals that are used, but only the chemical names (not their reactions) were provided.	**0 pts** **No Marks/Not Addressed**
Integrates and synthesizes different types of knowledge: This indicator is used to assess how well teams integrated the knowledge of reactor design and consumer/community demand in order to enhance the commodity production process.	**10 pts** **Exceptionally Proficient** The guidelines were exceeded in that the team indicated that there was a demand, provided a reason for the demand, and included quantitative data regarding the trends in demand and how these trends might influence the process, including the operational parameters of the reactors, the availability of raw materials, or the overall process. The information that was presented was properly referenced or justified in a convincing manner.	**8 pts** **Proficient** The basic guidelines were met in that the team indicated that there was a demand for the product, and some justification for the conclusion was made through the use of references. However, a connection to the process (e.g. raw materials availability) was either not made or was minimally addressed.	**4 pts** **Below Proficient** The team indicated that there was a demand for the product, but provided very minimal justification for the conclusion, and did not link back to the reactors and the process.	**0 pts** **No Marks /Not Addressed**

Table 2: Assessment Rubrics: Presentation- 2021 Implementation			
Criterion	Ratings		
Integrates and synthesizes different types of knowledge: This indicator is used to assess how well teams integrated the knowledge of the various aspects of the process and synthesized this information into a presentation.	**Highly Recommend** The team provided a presentation that synthesized the various pieces of information regarding the process, including all elements of the process, especially the connection to reactor design and use. The presentation was well executed, exceptionally engaging, and complete in all ways.	**Recommend** The team provided a presentation that synthesized the various pieces of information regarding the process, including all elements of the process, especially the connection to reactor design and use.	**Missing Elements** The team created a presentation, but elements were missing, and the process was not sufficiently described.

Table 3: Assessment Rubrics: Presentation- 2023 Implementation			
Criteria	Prompt	Likert Scale Rating of 5	Likert Scale Rating of 1
Integrates and synthesizes different types of knowledge: This indicator is used to assess how well teams integrated the knowledge of the various aspects of the process and synthesized this information into a presentation.	Please evaluate the content included in the presentation. A score of 5 is the best and highest possible score, and indicates that the team did an excellent job. A score of 1 is the lowest score.	The presentation provided pertinent facts and sufficient content so that the process was clearly understood.	The presentation did not provide sufficient content to understand the process.
	Please evaluate the organization of the presentation. A score of 5 is the best and highest possible score, and indicates that the team did an excellent job. A score of 1 is the lowest score.	The presentation was highly organized and therefore was easy to follow.	The presentation was not organized and therefore was difficult to follow.
	Please evaluate the creativity of the presentation. A score of 5 is the best and highest possible score, and indicates that the team did an excellent job. A score of 1 is the lowest score.	The presentation was not creative or engaging.	The presentation was not creative or engaging.
	Please evaluate the effectiveness of the delivery. A score of 5 is the best and highest possible score, and indicates that the team did an excellent job. A score of 1 is the lowest score.	The presentation was highly effective and sparked additional interest.	The presentation would have benefitted substantially from a different delivery approach in order to enhance its effectiveness.

Figure 1: Jamboard outputs from a group of students in the 2021 implementation of the *Initial Intervention.*

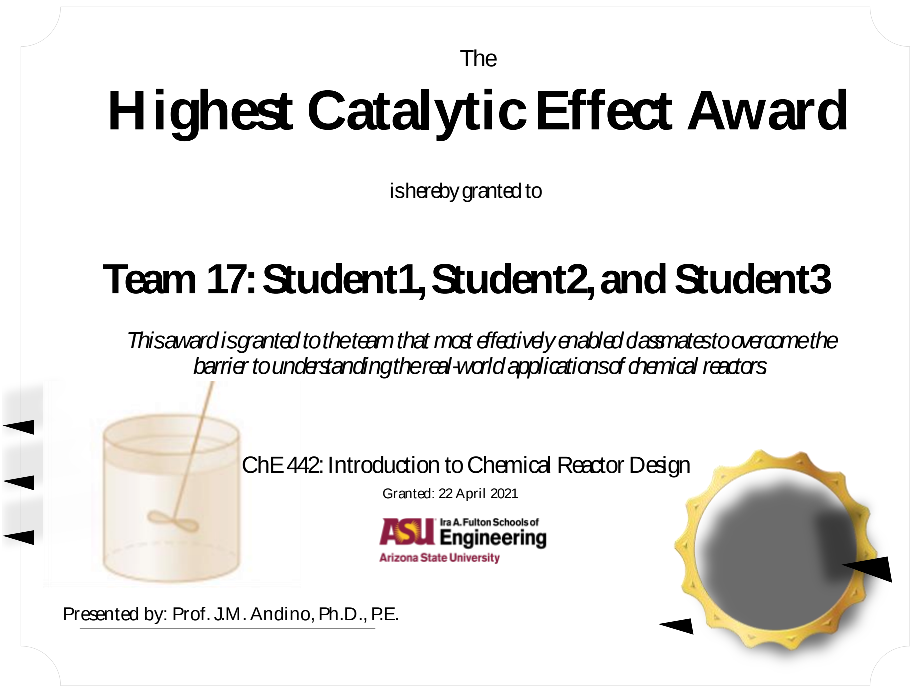

Figure 2: Example award provided in the *Creative Intervention* phase.