

Learning and Soft Skills Development in Chemical Engineering Practice School Students Using AIChE National Student Design Competition Problems

Abstract

Chemical Engineering Practice School (ChEPS) at King Mongkut's University of Technology Thonburi (KMUTT) in Thailand is a two-year international Master's program that emphasizes practical training and soft-skill development. The curriculum requires one semester of compulsory internship. To prepare students for internships, team design projects are integrated into some courses. For the first time, AIChE National Student Design Competition (NSDC) problems were used to train 19 ChEPS students in a competition format. A total of three NSDC problems were used. The students were divided into six teams, with two teams being assigned to the same project to compete for a better solution. A panel of three referees from ChEPS and from outside KMUTT judged the teams based on four oral presentations. The effectiveness of this new format was subsequently assessed via group interviews and surveys. Qualitatively, the interviews showed that most students believed the new format had helped them in key learning areas such as English proficiency and problem-solving. On the other hand, the surveys asked the students and the judges to quantitatively rate the new format in a number of key areas pertaining to learning. The survey results showed that on a scale of 1 to 10 with 10 representing the most positive outcome, the average scores were larger than 7, which indicated a high degree of success in using AIChE NSDC problems. Finally, both the students and the judges overwhelmingly recommended that this AIChE NSDC Competition be continued next year for the next class of ChEPS students.

Introduction

Chemical Engineering Practice School (ChEPS) is a practice-based international Master's program at King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok, Thailand. ChEPS was established in 1998 as a flagship curriculum modeled after David H. Koch School of Chemical Engineering Practice at Massachusetts Institute of Technology (MIT) in the US (Johnston et al., 1994). ChEPS is one form of work-integrated learning (WIL) which has proven successful in training students in higher education (Dressler and Kneeling, 2004; Patrick et al., 2009; Thonglek et al., 2011). The ChEPS curriculum comprises two years and one summer as shown in Figure 1. There is no coursework in the second year. Instead, students are required to undertake a short one-semester thesis and one semester of practical training at a sponsoring company (Ku et al., 2007).

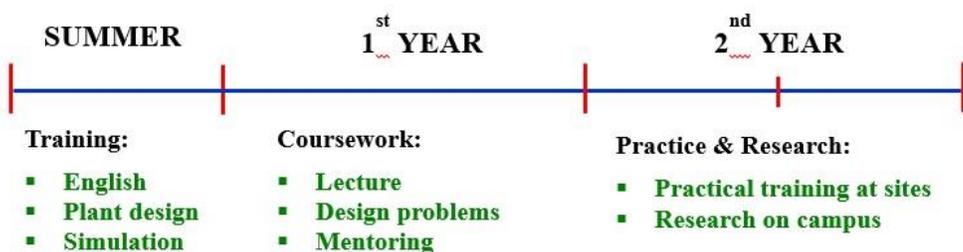


Figure 1. Timeline of the ChEPS Curriculum

The mission of ChEPS is twofold. One is to introduce Western-style education, which tends to focus more on critical thinking and problem-solving, into an engineering program. Because a conventional curriculum usually emphasizes only technical contents, another goal of ChEPS is to produce well-rounded chemical engineering graduates who are also well-versed in soft skills. Soft skills are personal attributes that are outside one's professional qualifications and work experience. These attributes govern how one interacts, leads, and communicates with others and are essential for any successful career. Companies have increasingly placed more emphasis on the importance of soft skills in their employees. Desirable soft skills often mentioned by Thai companies who employ engineers

include teamwork and people skills, maturity, English proficiency, presentation skill, technical report writing skill, and problem-solving skill.

As a result, the ChEPS program has constantly sought novel ways to augment ChEPS students' academic work with soft-skill training. The methods include Lego Logo workshops, mind-mapping techniques, writing workshops, and English tutoring, all of which have proven effective to a certain extent. On the other hand, ChEPS has found that implementing team design problems in certain core chemical engineering courses in the first year is the most successful format in helping students develop their soft skills and preparing them for internship (Ku and Thonglek, 2011). The reason is that design problems are multifaceted, offering various avenues for improving students in such skills as problem-solving, teamwork, communications, and project management. Consequently, team design projects are integrated into three courses taught in the summer and two semesters of the first year.

The first course (CHE655) in the eight-week summer typifies a standard plant design project and involves design and economic evaluation of a commercial process that produces common chemicals such as acetone, ethanol, cumene. This course has no lecture since incoming ChEPS students are expected to have taken an undergraduate plant design course. Instead, technical and English advisors are assigned to each team. Aspen Plus is used to aid with the simulation and design. A total of four oral presentations is mandatory, consisting of a proposal presentation, two progress presentations, and a final presentation. A final report must also be submitted at the conclusion of the project.

The remaining two courses (CHE656 and CHE657) have a similar format except that their technical contents are split evenly between lecture and design problems. The subjects in CHE656 and CHE657 are process dynamics and process optimization, respectively. Lectures are given during the first half of a semester while design problems are carried out during the second half. Each design team consists of either three or four students. Design problems in CHE656 and CHE657 in the past have generally come from published papers in the field of simulation and modeling and from real-life industrial problems provided by ChEPS' industrial sponsors.

Each type of design problems has its advantages and disadvantages. Published problems tend to be self-contained in which final results are given, while industrial problems tend to be more open-ended. Literature problems are by nature more complex, requiring more in-depth analyses and often involving complicated theories and calculations. On the other hand, industrial problems offer more realistic statements under more authentic conditions, but they sometimes suffer from missing or incomplete input and a lack of experimental data that can be used to validate hypotheses. As a result, ChEPS must constantly weigh the trade-off between the two types of design problem and seek the right balance.

ChEPS Design Problem Competition

American Institute of Chemical Engineers (AIChE), the world's leading non-profit organization for chemical engineering professionals, has been running its National Student Design Competition (NSDC) since 1932. Each year, chemical engineers from a designated company devise an undergraduate contest problem that typifies a real, working, chemical engineering design situation. The solution of the problem requires a wide range of skills in calculation involving both technical data and economic considerations. Up to three winning solutions, namely 1st, 2nd, and 3rd places, will be determined for individual entries and for team entries by a panel of judges.

AIChE NSDC problems offer the best of the two worlds as design problems within the ChEPS curriculum. First, NSDC problems are based on commercially viable processes because they come from engineers and technologists of real companies. Moreover, NSDC problems have the advantage of being open-ended with no single right answer and are hence conducive to team competitions. Furthermore, not all input data are provided, and so students must make reasonable assumptions and do their best to search for the missing information. Finally, AIChE has in the last few years put forward contest problems that depart from traditional chemical engineering and focused more on topics that are related to biotechnology and biological and environmental engineering. This is an added advantage since today's chemical engineers are no longer confined to the traditional lines of work in the discipline.

While AIChE NSDC problems seem ideal for training ChEPS students, past problem statements were not readily available until recently when AIChE started posting them on the Internet (AIChE, n.d.). Internet denizens can now freely download all NSDC problems statements dating back to 1932. As a result, starting with the academic year 2014, ChEPS decided to incorporate AIChE NSDC problems into CHE656 for the first time. The three problems chosen were:

- Year 2000: Process Synthesis and Design of the Power Generation System for Automobiles: A Fuel Cell Approach
- Year 2007: Separation Technology Evaluation for Economic Recovery of Pyridine
- Year 2013: Comparison of Bio-mass to Bio-oils Reactor Systems: Direct Conversion vs. Companion Coal Gasification

The 19 ChEPS students in Class-18 were randomly divided into six teams with three or four members per team. Two teams were randomly assigned the same NSDC problem and were instructed to compete against one another to come up with a better solution. Four oral presentations were set, namely one proposal presentation, two progress presentations, and one final presentation. Each of the first three presentations accounts for 20% of the total points in the competition, while the last presentation accounts for 40%. Every student was required to participate in all the presentations.

Faculty members in ChEPS took turn serving as members of a three-judge panel who graded the oral presentations. Note that the ChEPS design problem competitions were judged based solely on the four presentations. The students' final reports are not part of the competitions because the reports are evaluated separately which become part of the final grades in CHE656. For the final presentation, three external judges were invited to sit in the panel. These three judges were the CEO of a small chemical company with a doctorate degree in chemical engineering, a senior PhD engineer from a sponsoring company, and a professor from another university in Bangkok.

Grading criteria were divided into three categories, namely Presentation, Content, and Question & Answers (Q & A), which represent 20%, 50%, and 30% of the total score, respectively, as shown in

Figure 2. Each category was further subdivided into subcategories to aid the judges in assessing the students' performance. The presentation of each team was choreographed to be about 40 minutes long. So to allow ample time for the judges to ask questions and offer critiques, each team was limited to 15 minutes of actual presentations. Immediately after one team had finished its presentation and concluded the Q&A session, each judge would take a moment to make some general comments about the team's performance in each category. Finally, all three judges would raise a small whiteboard showing the overall score (based on a maximum of 100 points) for that team. Although the instant scoring put the students in the spotlight, it has the benefit of allowing the students to relate the outcome of the Q&A session and the critiques made by the judges to the score they received. It was hoped that this connection would better imprint into the students' minds about the strengths and weaknesses in their performances.

Finally, at the end of the eight-week competition, a winner was declared at the conclusion of the final presentation for each NSDC project. The three winning teams were then ranked based on the cumulative scores of the four presentations. The 1st place winner received a prize money of 3,000 baht (about 100 US dollars), while the 2nd place and the 3rd place winners received 2,000 baht and 1,000 baht, respectively.

Methodology for Assessing the New Format

The success of the new design project format was evaluated based on two methods, namely reflections and surveys. ChEPS has a faculty member with a doctorate degree in engineering education and WIL. Soon after each presentation, this faculty member conducted a group interview or reflection session with each team. The objective was to collect feedback from the students on issues pertaining to their learning from the design projects. In addition, both the students and the judges were asked to participate in a survey after the final presentation to quantitatively assess the effectiveness of using NSDC problems. In the questionnaires, the students and the judges were asked to indicate if they liked or disliked a certain aspect of the new format using a scale from 1 to 10, with 10 being most satisfied with the outcome of that aspect.

Reflections (Boud, 1999, Boud et al., 1985a, 1985b) have proven to be effective in enhancing student learning. Reflections allow students to provide feedback to a WIL program on all aspects of their learning while undergoing soft-skill and practical training. The feedback is useful in allowing the program and its academics to be alerted to potential problems and to further improve its organization and management. For the AIChE NSDC competition, each of the six competing teams underwent a total of four group interviews, each taking up about half an hour. Recording and note-taking were used to capture the essence of all the feedback. While group interviews involved both students and academics, reflection was an individual effort. Bolton (2005) has found reflection to be an important part of student learning. Reflective practice is generally used as a tool to disclose what and how students learn during their soft-skill developments. Reflection could also be employed to reveal students' attitudes and their abilities to learn independently. Reflection in the form of writing usually involves keeping a diary and answering a set of trigger questions. Examples of trigger questions are (Thonglek 2014):

- *What actually happened during a specific learning experience?*
- *What was its impact on you personally?*
- *What did you learn from the experience?*
- *What lesson did you learn that would make you become a better engineer?*

For the AIChE NSDC competition, a one-page reflection sheet shown in Figure 3 was distributed to all students at the end of each presentation to allow them to freely and anonymously express their opinions about every aspect of the new presentation format.

While interviews and reflections are useful for assessing student learning, they are qualitative in nature. As a result, a survey in the form of questionnaires was also conducted. The questionnaires asked the students and the academics (Figure 4 and Figure 5, respectively) to rate several aspects of the AIChE competitions, e.g. the competition format, the nature of the AIChE problems, impact on self-learning, and feedback from the judges. A scale from 1 to 10 was used, with 10 representing the most positive outcome. Similar to the questionnaires in the reflections, the survey was also anonymous.

Results and Discussion

Results from the group interviews and personal reflections showed that the students generally found the new design project format to be better than the old one in terms of assisting them with learning. The learning benefits offered by the new format can be summarized as follows:

1. *Self-learning.* Unlike the old format, there were no technical advisors assigned to design groups. Instead, team members must rely on each other through brain-storming and group discussion to solve problems at every stage of the project. In some cases, the students must study new concepts and theories which were advanced or were never taught in classroom. For example, the chemical process simulator called Aspen Plus was used in some projects. While the students had studied process simulation and had used the software before, some of them must use more advanced features such as solids handling in their projects. All of these obviously resulted in more and better independent learning.
2. *Teamwork.* Without a project advisor, students in a team often had to interact more which fostered better teamwork. There was no longer a “referee” who could mediate on behalf of students when conflicts of opinions arose. Consequently, students must learn to cooperate and resolve their differences among themselves.
3. *Technical challenges.* The students found the AIChE NSDC problems to be technically more challenging than those found in the old format. AIChE problems tend to be more diverse, open-ended, and yet practical, while a typical plant design project follow a rather routine set of calculations. So it is not surprising that the students actually learned more and were more intellectually engaged when working on AIChE problems.
4. *Critiques and feedback.* Because a new evaluation system had been devised based on a set of very specific criteria rather than being holistic like in the past, the judges sitting in a presentation were able to quantitatively assess the progress in each project. Since all judges must ask questions during the Q&A session and were required to make concluding remarks at the end of

each group presentation, they were able to offer more critical yet useful comments based on the points awarded in the evaluation sheet.

On the other hand, a number of students expressed some reservations about the AIChE competitions during the interviews and reflections. First, there was the issue of the competition itself which had caused stress and put some students under pressure. Second, while a lack of project advisors did promote self-learning, some students were concerned that without proper guidance their project could be going in the wrong direction or that their entire problem-solving methodology was wrong. Finally, almost every student mentioned time constraint as an obstacle. This is understandable, given the heavy workload in the other four courses, some of which even required additional group-based projects that had different member make-ups. So the students had to constantly shuffle from one group meeting to another. Despite these issues, all students agreed that the new format was helpful with their learning.

Surprisingly, the make-up of team members with respect to academic strength was never construed as a problem by the students, although in one of the three head-to-head competitions, the two teams were clearly not evenly matched. When prodded, the disadvantaged team opined that they were not hopeful about winning the competition, but instead saw this an opportunity to work harder and learn more. One student in that team felt that she was able to contribute significantly more this time than she did in the previous design project which had much stronger members. In the end, the fact that all six design teams were created based on random drawings probably entailed a sense of fairness among the students.

Results from Question 1 in the questionnaire of the survey in Figure 4 and Figure 5 show the following top five skills that are believed to have improved significantly as a result of the AIChE NSDC competition: 1. Technical knowledge (22 votes), 2. Teamwork (22 votes), 3. Oral presentation (21 votes), 4. Problem solving (19 votes), and 5. Report writing (18 votes). The skills in the remaining four areas, namely English proficiency, systematic thinking, engineering judgment, and communication, received 16, 13, 12, and 10 votes, respectively.

Table 1 shows the results from Question 2 through Question 5 in the questionnaire. Five key aspects of the AIChE NSDC Competitions were identified and shown in Column 1 of Table 1. Since all of the average scores in Table 1 are larger than 7.0, it is obvious that both the students and the academics found the new AIChE NSDC Competitions to be a valuable tool for assisting the students with their learning and soft-skill development. Finally, the survey showed that the students and ChEPS faculty unanimously would like to see this competition format being continued for future ChEPS classes.

Aspects of AIChE NSDC Competition Format	Average, Low, High, and SD Scores by Students* (1 – 10)	Average Scores by ChEPS Faculty** (1 – 10)
Overall AIChE NSDC Competition Format	7.58; 5; 10; 1.46	8.60
Technical Challenges of AIChE NSDC Problems	7.63; 5; 10; 1.34	8.40
Impact on Self-learning	8.42; 4; 10; 1.74	N/A
New Presentation Evaluation System	N/A	8.40
Feedback and Critiques by Competition Judges	7.95; 6; 10; 1.13	9.00

Table 1. Results of the Quantitative Survey of the AIChE NSDC Competition

* Based on a total 19 students in Class18.

** Based on a total of five competition judges.

Conclusions

Well-rounded graduating engineers are those who possess both technical competency and soft-skill attributes. These engineers are understandably some of the most sought-after prospective employees by companies. For 18 years, Chemical Engineering Practice School or ChEPS at King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok, Thailand, has been tasked with the mission of producing some of the best and well-rounded Master's students to serve the country's chemical and petrochemical industries. As a result, team design projects are an integral part of the ChEPS curriculum. These design problems help ChEPS students hone their skills in teamwork, project management, presentation, and technical writing.

Design problems are integrated into three courses in the first year of the ChEPS curriculum. In the past, these design problems have come from a variety of sources. Each type of design problems has its advantages and disadvantages, but by and large their implementations have been rather successful. In spite of that, starting with Class-18 in 2014 ChEPS pioneered the use of AIChE NSDC problems in the form of competitions to further improve the effectiveness of this learning paradigm.

Group interviews, personal reflections, and surveys were carried out to assess the effectiveness of the new design project format when compared to the old format. Interviews and reflections gave qualitative results which indicated students' overwhelming approval of the new format. Quantitative survey results from the students and faculty correlated well with the qualitative findings. In summary, both types of results from this study strongly indicated that using AIChE NSDC problems could vastly enhance the development of chemical engineering students' learning and soft skills.

Future research

The use of AIChE NSDC problems to develop students' soft skills is pioneering so a lot of work remains to be done. To fully realize the benefits of NSDC problems, "coaches" should be appointed in future competitions to help students with their presentations and Q&A, the latter being consistently the weakest point seen in all students. Regular coaching sessions should be conducted throughout the duration of the competition. In addition, the random drawings of students to form teams, while fair, poses a different problem. It is likely that, given so many teams, some pairs facing each other are not evenly matched academically. Some weaker teams could be disheartened from the start, resigning to the fact that they have little chance of beating the other much better team. A simple solution would be to "seed" each team with one (or perhaps two) academically strong student. The remaining team members could still then come from drawings to ensure a certain degree of fairness. On the other hand, the appearance of having two academic tiers in such a small program as ChEPS may invoke some animosity among students. In the end, there is no perfect solution, and ChEPS reserves the right to exercise judgment on certain aspects of the competitions.

CHE656 AIChE NSDC Competitions Evaluation Sheet

1st Presentation, Sept 18, 2014 Judge's Name: _____

Instruction: Please use a scale of 1 to 10 to award points in the matrix.

Category 1: Presentation (20%)

	Oral Presentation (10 Points)	Slides (10 Points)	Subtotal (20 Points)
Group 1			
Group 2			
Group 3			
Group 4			
Group 5			
Group 6			

The 3 competition projects are:

- From Year 2000:** Process Synthesis and Design of the Power Generation System for Automobiles: A Fuel Cell Approach
- From Year 2007:** Separation Technology Evaluation for Economic Recovery of Pyridine
- From Year 2013:** Comparison of Bio-mass to Bio-oils Reactor Systems:

Category 2: Content (50%)

	Data (10 Points)	Systematic Thinking (10 Points)	Technical Accuracy (10 Points)	Practicality (10 Points)	Analysis & Discussion (10 Points)	Subtotal (50 Points)
Group 1						
Group 2						
Group 3						
Group 4						
Group 5						
Group 6						

Category 3: Q & A (30%)

	Confidence (10 Points)	Correctness (10 Points)	Communication (10 Points)	Subtotal (30 Points)	Grand Total (100 Points)	
Group 1						
Group 2						
Group 3						
Group 4						
Group 5						
Group 6						

Figure 2. AIChE NSDC Competition Evaluation Sheet

Presentations:

Proposal

Progress I

Progress II

Final

Students' Feedback for CHE656 Design Problems

- How do you feel about this new format of Design Problem?
 - Like** it because _____
 - Do not like** it because _____
 - Feel indifferent** _____
- Does this new format help you feel more engaged in learning?
 - Yes _____
 - No _____
- What do you **like the most** about solving Design Problems? _____
- What do you **like the least** about solving Design Problems? _____
- What do you **like the most** about this new NDSC format? _____
- What do you **like the least** about this new NDSC format? _____
- Additional comments: _____

Figure 3. Questionnaires for Personal Reflections on AIChE NSDC Competition

AICHe NSDC Competition Survey Questions

(For Students)

- What skills do you think you have benefited from the Design Problems (check all that apply)?

<input type="checkbox"/> Technical knowledge	<input type="checkbox"/> Teamwork	<input type="checkbox"/> English proficiency
<input type="checkbox"/> Oral presentation	<input type="checkbox"/> Report writing	<input type="checkbox"/> Systematic thinking
<input type="checkbox"/> Problem solving	<input type="checkbox"/> Communication	<input type="checkbox"/> Engineering judgment
<input type="checkbox"/> Others Please specify: _____		
- On a scale of 1 – 10 with 10 being the most positive, how do you feel about the new AICHe NSDC Competitions format in CHE656 when compared to the old format in CHE654?

1 2 3 4 5 6 7 8 9 10

Very Negative > Barely Positive > Somewhat Positive > Mostly Positive > Very Positive
- On a scale of 1 – 10 with 10 being the most positive, how do you like the AICHe NSDC problems in CHE656 when compared to plant design projects in CHE654 in terms of their technical challenges?

1 2 3 4 5 6 7 8 9 10

Very Negative > Barely Positive > Somewhat Positive > Mostly Positive > Very Positive
- On a scale of 1 – 10 with 10 being the most helpful, how does the new format of AICHe NSDC Competitions in CHE656 without academics' supervision foster the development of your self-learning?

1 2 3 4 5 6 7 8 9 10

Not Very Helpful > Barely Helpful > Somewhat Helpful > Mostly Helpful > Very Helpful
- On a scale of 1 – 10 with 10 being the most useful, how do you view the comments and feedback given by the judges in the AICHe NSDC Competitions in CHE656 when compared to those given in the plant design projects in CHE654?

1 2 3 4 5 6 7 8 9 10

Not Very Useful > Barely Useful > Somewhat Useful > Mostly Useful > Very Useful
- Would you recommend that this AICHe NSDC Competitions be continued next year for the next class of ChEPS?

Yes No
- Other comments:

Figure 4. AICHe NSDC Competition Survey Questions for Students

AICHe NSDC Competition Survey Questions

(For Competition Judges)

- What skills do you think the students have benefited from the Design Problems (check all that apply)?

<input type="checkbox"/> Technical knowledge	<input type="checkbox"/> Teamwork	<input type="checkbox"/> English proficiency
<input type="checkbox"/> Oral presentation	<input type="checkbox"/> Report writing	<input type="checkbox"/> Systematic thinking
<input type="checkbox"/> Problem solving	<input type="checkbox"/> Communication	<input type="checkbox"/> Engineering judgment
<input type="checkbox"/> Others Please specify: _____		
- On a scale of 1 – 10 with 10 being the most positive, how do you feel about the new AICHe NSDC Competitions format in CHE656 when compared to the old format in CHE654?

1 2 3 4 5 6 7 8 9 10

Very Negative > Barely Positive > Somewhat Positive > Mostly Positive > Very Positive
- On a scale of 1 – 10 with 10 being the most positive, how do you like the AICHe NSDC problems in CHE656 when compared to plant design projects in CHE654 in terms of their technical challenges?

1 2 3 4 5 6 7 8 9 10

Very Negative > Barely Positive > Somewhat Positive > Mostly Positive > Very Positive
- On a scale of 1 – 10 with 10 being the most useful, how useful are the new assessment criteria of AICHe NSDC Competitions in CHE656 in helping you judge the quality of students' work and oral presentations?

1 2 3 4 5 6 7 8 9 10

Not Very Helpful > Barely Helpful > Somewhat Helpful > Mostly Helpful > Very Helpful
- On a scale of 1 – 10 with 10 being the most useful, how do you view the comments and feedback given by the other judges in the AICHe NSDC Competitions in CHE656 when compared to those given in the plant design projects in CHE654?

1 2 3 4 5 6 7 8 9 10

Not Very Useful > Barely Useful > Somewhat Useful > Mostly Useful > Very Useful
- Would you recommend that this AICHe NSDC Competitions be continued next year for the next class of ChEPS?

Yes No
- Other comments:

Figure 5. AICHe NSDC Competition Survey Questions for Competition Judges

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