Implementation of State-of-the-Art Learning Tools in the School of Engineering at Nazarbayev University in the Post-Soviet Republic of Kazakhstan

Ms. Sayara Saliyeva, Nazarbayev University  
Dinara McLaughlin  
Dr. Moulay Rachid Babaa, Nazarbayev University

Dr. Moulay Rachid Babaa received his M.E. in Chemical Processes in 2001 from Blaise Pascal University, Clermont-Ferrand France and Ph.D. in Materials Science and Engineering in 2004 From Henri Poincare University, Nancy France. He has been a postdoctoral fellow at Laboratoire des Colloides Verres et Nanomateriaux CNRS in Montpellier, France. He also worked as a senior researcher at the Institut Rayonnement Matière de Saclay at the French Atomic Energy Commission (CEA). Currently, he is an associate professor of Chemical Engineering in the School of Engineering at Nazarbayev University, Astana, Kazakhstan. His interests involve the synthesis, surface modification and assembly of nano-materials (carbon nanotubes, nano-particles, nano-composites) and the study of their physical properties.

Dr. Hella Tokos, Nazarbayev University

Hella Tokos is an Assistant Professor of Chemical Engineering at Nazarbayev University.

Prof. Stefaan Jan Rogier Simons, University College London

Professor Simons was the founding dean of the School of Engineering at Nazarbayev University (NU), on secondment from University College London, a strategic partner of NU. He is now the Director of UCL’s International Energy Policy Institute at their campus in Adelaide, Australia.

Prof. Sarim Naji Al Zubaidy, Nazarbayev University

Sarim Al-Zubaidy is Vice-Dean (Teaching Learning) at the School of Engineering, Nazarbayev University, Kazakhstan. He has over thirty year experience in both senior academic and administrative positions in a variety of higher education institutions around the world. He has authored over 100 peer reviewed articles and technical papers. His expertise ranges from traditional to newly formed universities to those in transition.

Dr. Joseph A. Menicucci Jr., Nazarbayev University

Joseph A. Menicucci, Jr. is an Assistant Professor of Chemical Engineering at Nazarbayev University.
Implementation of State-of-the-Art Learning Tools in the School of Engineering at Nazarbayev University in the Post-Soviet Republic of Kazakhstan

Sayara Saliyeva\textsuperscript{1, 2}, Dinara McLaughlin\textsuperscript{3}, Moulay Rachid Babaa\textsuperscript{1}, Hella Tokos\textsuperscript{1}, Stefaan Simons\textsuperscript{4}, Sarim Al-Zubaidy\textsuperscript{5}, and Joseph Anthony Menicucci Jr.\textsuperscript{1, \textdagger}

\textsuperscript{1}. Department of Chemical Engineering, School of Engineering, Nazarbayev University. 53 Kabanbay Batyr Avenue, Astana, Kazakhstan 010000; \textsuperscript{2}. School of Energy and Resources, UCL-Australia, University College London. Torrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia; \textsuperscript{3}. Department of Civil Engineering, School of Engineering, Nazarbayev University. 53 Kabanbay Batyr Avenue, Astana, Kazakhstan 010000; \textsuperscript{4}. International Energy Policy Institute, UCL Australia, University College London. Torrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia; \textsuperscript{5}. School of Engineering, Nazarbayev University. 53 Kabanbay Batyr Avenue, Astana, Kazakhstan 010000; \textsuperscript{\textdagger} Corresponding Author (jmenicucci@nu.edu.kz).
Introduction

In 2011, the School of Engineering at Nazarbayev University accepted its first cohort of students. The core building-blocks of the School of Engineering at Nazarbayev University are: problem-centered learning, the ‘upside-down’ curriculum, mathematics in context, design orientation, and combining simulation with laboratory and workshop practices. These core building-blocks are all connected through the central themes of safety and sustainability, transferable skills development, and management and entrepreneurship.

The School of Engineering’s teaching program has been developed in partnership with University College London, considered one of the world’s best universities. Students are taught in an “engineering systems” fashion, with all first year modules common with the exception of an elective and an introductory course in each specific discipline. The curriculum was developed after a “needs analysis” identified the attributes desirable to companies looking for engineers in the Republic of Kazakhstan.

Most aspects of higher education in the Republic of Kazakhstan are prescribed by the Ministry of Education, including courses to be taught and texts to be used. Nazarbayev University is the first in the Republic of Kazakhstan to be developed in a “western style” without Ministry approval of the curriculum. A Rodriguez-Falcon study\(^1\) highlights the significant cultural differences between the western mindset and the mindset of students from Asian backgrounds, as found in the Republic of Kazakhstan. Specifically, students from numerous Asian countries listed issues related to respecting authority as very important whereas students from western cultures identified that maintaining positive relationships with their colleagues was much more important. Because the School of Engineering and Nazarbayev University are operating on a western module of education, attention is consistently being paid on preventing potential conflicts between the Asian and Western value systems\(^2\).

In order to support the core-building blocks of the School of Engineering at Nazarbayev University, a number of state-of-the-art learning tools have been implemented into the engineering curriculum, including: a Virtual Chemical Vapor Deposition Laboratory\(^3, 4, 5\), Concept Tests from the AIChE Concept Warehouse\(^6, 7, 8\), and Elevator Pitches\(^9, 10, 11, 12\).

The Virtual Chemical Vapor Deposition laboratory was introduced in a course entitled Engineering Systems Laboratory 0. This course was offered in the first semester of instruction at Nazarbayev University. It, like all other modules in this semester, was taken by all engineering students as part of the engineering-systems inspired curriculum. This virtual laboratory, however, was the only laboratory performed by the students in their first semester in the School of Engineering. Though it will not be offered again in this format, the general objectives of Engineering Systems Laboratory 0 were integrated into Engineering Systems Laboratory, a ten-
laboratory course that will be taken by all engineering students in the second semester of their second year in the School of Engineering at Nazarbayev University. The aim of this course was to teach students how to analyze experimental data and interpret results. At the successful completion of the course, students are expected to be able to:

- analyze a problem,
- state an experimental objective,
- develop and implement an experimental plan,
- analyze data for statistical significance,
- draw conclusions from experimental data, and
- write a technical report.

Engineering in Society is an elective course that was first offered in the fall semester of the second academic year of the school of engineering at Nazarbayev University. 36 students participated in this elective in a semester that was otherwise uniform for all second year engineering students. The course was then offered as an elective for first year students in their second semester starting in the 2012-13 academic year. 100 students enrolled in the course in its second offering. The aim of this course is to act as an introduction to engineering ethics while also exploring the societal impact of engineering projects and developing written and verbal communications skills. At the successful completion of this course, students are expected to be able to:

- evaluate and explain the position and responsibilities of the engineer in relation to industry and society,
- identify with ethical values in the profession,
- explain the importance of minimizing impacts on the environment,
- critically evaluate the environmental planning process, and
- communicate engineering proposals to a non-technical audience.

Engineering Thermodynamics is taken by all engineering students in their first semester in the school. It is one of many foundational courses taken by all engineering students in their first three semesters within the school. A full list of all courses completed by our first cohort of chemical engineering students through their first two years at Nazarbayev University is found in Table 1. Those courses that are common to all engineering students are italicized. The aim of engineering thermodynamics is to introduce the basic principles of thermodynamics and their applications. At the successful completion of this course, students are expected to be able to:

- appreciate the importance of thermodynamics as a science enabling engineers to quantitatively analyze machines used to convert energy into useful work, and
- use the laws of thermodynamics to:
improve the effectiveness with which energy resources may be used;
- determine efficiencies of machines and processes;
- evaluate the viability of new processes; and
- calculate energy losses as a result of inefficient operation of equipment.

Table 1: Two Years of Chemical Engineering at Nazarbayev University

<table>
<thead>
<tr>
<th>Engineering Mathematics I</th>
<th>Engineering Mathematics II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Thermodynamics</td>
<td>Systems Modeling and Control</td>
</tr>
<tr>
<td>Fluid Mechanics</td>
<td>Energy Studies</td>
</tr>
<tr>
<td>Industrial Talks</td>
<td>Engineering Materials</td>
</tr>
<tr>
<td>Engineering Systems Laboratory 0</td>
<td>Engineering Elective I</td>
</tr>
<tr>
<td>Critical Issues in the Humanities</td>
<td>Interdisciplinary Design Project</td>
</tr>
<tr>
<td>Engineering Systems Design I</td>
<td>Engineering Systems Laboratory</td>
</tr>
<tr>
<td>Basic Mechanics</td>
<td>Chemical Engineering Fluid Mechanics</td>
</tr>
<tr>
<td>Engineering Circuits and Devices</td>
<td>Chemical Reactions and Thermodynamics</td>
</tr>
<tr>
<td>Engineering Systems Design II</td>
<td>Heat and Mass Transfer</td>
</tr>
<tr>
<td>Modeling and Software Development</td>
<td>Particulate Systems</td>
</tr>
<tr>
<td>Introduction to Chemical Engineering</td>
<td></td>
</tr>
</tbody>
</table>

Learning Tool Implementation

Virtual Chemical Vapor Deposition in *Engineering Systems Laboratory 0*

An introductory laboratory module encompassing topics related to Engineering Thermodynamics and Engineering Fluid Mechanics was scheduled to be offered in the second half of the first semester of the first academic year at Nazarbayev University. When the laboratories were not ready on schedule, a course was designed and delivered that utilized the Virtual Chemical Vapor Deposition Laboratory developed at Oregon State University.

In this course, students were engaged in project-based learning of an open-ended nature. This challenged them to think about design of experiments and involved an economic component that ensured that they balanced their desire to optimize experimental results with the economic cost of doing so. The students also received written and verbal feedback that significantly improved their ability to prepare a formal report. As an engineering systems design course, the systems approach was utilized for attaining student achievement goals. All research groups were multi-
disciplin ary by instructor design. The project offered high-achieving students the opportunity to enhance their own learning and the project necessitated the students taking responsibility for their own learning. In lieu of having any upper level support from an advanced cohort, students were also given support by a technician with an earned BEng in Chemical Engineering.

In academic year 2010-11, this cohort of students completed, on-site, a preparatory year managed by University College London. Students interested in pursuing a degree in engineering at Nazarbayev University must take four year-long courses in this foundation year: English for Academic Purposes, Science in Society, Mathematics, and Physics. Students completing these courses earn a numerical mark ranging from 0-100.

Because almost all of the course assignments are both project-based and open-ended, the corresponding author felt it necessary to balance groups as much as possible. To do so, he used the scores from the foundation program to ensure each group of 3-4 students had a balance of high, middle, and low performers. Each group had at least one student who had (preliminarily) selected chemical engineering as their specialization and each group had at least three disciplines represented.

The course was structured in a format such that, in addition to delivering lectures on chemical vapor deposition, design of experiments, and data analysis, the corresponding author also acted as a technical consultant for each group. Each group was required to submit short (typically 1-2 page) memos regularly to ensure they would be able to receive feedback before submitting the final report. Because of the condensed schedule (the laboratory course was scheduled to take place in the second half of the semester) and because of the instruction needed before students could begin (virtual) experimentation, the course assessment (memos, homework, final report, and take-home exam) took place over a one-month timeframe. In lieu of a final exam, the module coordinator gave each group a take-home “exam” where the following question was posed:

*It seems that a second Virtual Chemical Vapor Deposition Reactor has been found by an operator at Astana Chips but there is no record of experiments ever being run in this reactor. It appears that this is an identical reactor to the one you have been working with, but there is no way to be sure unless the reactor is tested. The purpose of this exam is to produce a short memo that clearly indicates whether this newly found reactor can be permanently used, without modification, at Astana Chips. You will be given a budget for experimentation to examine this reactor and will be tasked with comparing the data collected in this reactor to that collected in the fully functional reactor at Astana Chips (the same reactor that you’ve used for all previous experiments). Although there are many statistical tools that could be used to actually evaluate, with a certain level of confidence, if the data collected in both reactors is the same; Astana Chips is currently*
only asking your group for a simple analysis of the new reactor. You can assume that the Virtual ellipsometer used in all experiments is the same.

As you can see in Figure 1, the reactor in the take home exam was not identical to the reactor used in previous (virtual) experimentation. The corresponding author utilized a component of the Virtual CVD reactor that allows the temperature to be changed in certain reaction zones within the reactor. Student groups who properly analyzed data were able to see that the temperature in Zone III was increasing each time the reactor was operated.

Figure 1. Sample of Student Work, Take-Home Exam, Virtual Chemical Vapor Deposition Laboratory.

Elevator Pitches in *Engineering in Society*

This course, offered as an engineering elective for the first cohort of engineering students in the second year of the School of Engineering at Nazarbayev University, served as an introduction to engineering ethics while also exploring the societal impact of engineering projects. The course also focused on the development of engineering communications, especially written and verbal communication methods.

Students prepared a four minute presentation on an engineering project of interest to The Republic of Kazakhstan. In addition to giving this presentation, students were allowed to give one (A4) handout to each member of the review panel which consisted of the two course
instructors and, in some instances, a teaching assistant. The top nine project presenters, as evaluated by course instructors, were selected to give a two minute “Elevator Pitch” to their classmates in order to “recruit” them to their project team. Each non-presenting student present at these elevator pitches, filled out a form that indicated the three projects they were most interested in working on and the three projects they were least interested in. All students were placed on a project that they indicated was of most interest to them.

The project teams were then given their final project statement:

\textit{Develop an engineering proposal for a non-technical audience. Outline the scope of your project and the impact of this engineering project on industry and society. Demonstrate a thorough awareness of the significance and impact of project in societal/global context, explicitly and insightfully addressing issues such as energy, economics, government regulation, etc.}

In addition to meeting these requirements, each team was required to submit an environmental impact assessment comparing their project to two viable alternatives. Table 2 lists the topics of the final projects in the Engineering in Society course.

<table>
<thead>
<tr>
<th>Table 2: List of Final Project Topics in Engineering in Society</th>
</tr>
</thead>
<tbody>
<tr>
<td>The International Motor Road Corridor: Western China-Western Europe</td>
</tr>
<tr>
<td>Alma Electricity Transmission Project</td>
</tr>
<tr>
<td>Creation of [a] Health Resort in [the] Alakol Region</td>
</tr>
<tr>
<td>Application of Photovoltaic Panels in [the] Mangistau Region of Kazakhstan</td>
</tr>
<tr>
<td>Thermosolar Power Plant in Southern Kazakhstan</td>
</tr>
<tr>
<td>Indoor Ski Center Astana</td>
</tr>
<tr>
<td>Seismic Solution for Almaty City</td>
</tr>
<tr>
<td>Astana Underground Park Project</td>
</tr>
<tr>
<td>Waste Management Facility in Astana, Kazakhstan</td>
</tr>
</tbody>
</table>

Concept Tests from the AIChE Concept Warehouse in \textit{Engineering Thermodynamics}

The Engineering Thermodynamics course is required of all first-year students in the School of Engineering at Nazarbayev University. The implementation of Concept Tests occurred in the first semester of the second year of the School of Engineering. All students in this second student cohort were given a pre-course learning styles assessment using Felder and Silverman’s Index of Learning Styles\textsuperscript{13} as well as a pre-course and post-course questionnaire that asked students to evaluate ten statements about their own perceptions of learning. Of these ten statements, three were designed specifically to address student perceptions of learning possibly addressed by concept tests:
Statement A: I need to understand the underlying concept before I can calculate an answer to a problem using an equation.

Statement B: I learn more from a correct answer than I do from an incorrect answer.

Statement C: I like solving conceptual problems more than calculating an answer to a problem using an equation.

Concept Tests from the AIChE Concept Warehouse website\textsuperscript{15} were integrated into lectures to supplement the corresponding author’s standard method of course delivery. The corresponding author implemented these tools using the “Think-Pair-Share” technique similar to that described by Felder and Brent\textsuperscript{14}. He emphasized a conceptual understanding throughout the course and reinforced its importance by including problems of a conceptual nature on both the mid-term and final exam.

Figure 2 shows the results of the Index of Learning Styles Assessment conducted prior to the Engineering Thermodynamics course. Fifty percent of the students were identified as active learners, sixty-seven percent as sensing, eighty-three percent as visual learners, and sixty-four percent as sequential learners. These percentages are similar to those found in other engineering institutions, although most studies found a higher percentage of active learners\textsuperscript{16, 17, 18, 19} than this study.

![Figure 2. Index of Learning Style Assessment of the Second Cohort of Engineering Students at Nazarbayev University.](image-url)
Figure 3 shows response of students to three statements in the pre- and post-course questionnaire. Results were given as a percentage of respondents as 134 students responded to all three of these questions in the pre-course questionnaire, but only 113 responded to all questions in the post course questionnaire. A much lower percentage (13%) of students responded post-course that they did not agree that they learn more from a correct answer than an incorrect answer than they did pre-course (28%) and the percentage of students that strongly agreed with the statement post-course (32%) was noticeably higher than in the pre-course assessment (19%). Figure 3d shows the average and standard deviation for both the pre-course and post-course student response for all three statements.

Three case studies of student perceptions of learning are given below. Case study 1 and 2 highlight a student with a strong preference for one learning style whereas case study 3 highlights a well-balanced student.

Case Study 1: Student X is well balanced between active and reflective learning as well as visual and verbal learning. They have a moderate preference for sensing, and a very strong preference for global learning. Prior to this course, they indicated that they agreed with Statement A. After this course, they strongly agreed with this same statement. They agreed with Statement B in both pre-course and post-course evaluation. Finally, they indicated neutrality on Statement C before the course but disagreed with it in post-course evaluation. Student X indicated that they believed pre-course that they would earn a “B” in the course but believed that they would earn a “C” post-course (but before the final exam). They earned a “C+” in the course.

Case Study 2: Student Y is also well balanced between active and reflective learning as well as visual and verbal learning. They have a moderate preference for global learning and a very strong preference for sensing. Prior to this course, they indicated that they strongly agreed with Statement A. After this course, they agreed with this same statement. They disagreed with Statement B in pre-course evaluation, but strongly agreed with it in post-course evaluation. Finally, they indicated neutrality on Statement C both pre-course and post-course. Student Y indicated that they believed they would earn an “A” in the course in both the pre-course and post-course (but before the final exam) assessment. They earned an “A” in the course.

Case Study 3: Student Z is well balanced in all learning styles. Prior to this course, they indicated that they agreed with Statement A. After this course, they strongly agreed with this same statement. They disagreed with Statement B in pre-course evaluation, but strongly disagreed with it in post-course evaluation. Finally, they strongly agreed with Statement C in pre-course assessment but were neutral in the post-course assessment. Student Z indicated that they believed they would earn an “A” in the course in both the pre-course and post-course (but before the final exam) assessment. They earned a “C+” in the course.
Figure 3. Pre-Course and Post-Course Student Self-Assessment of Learning.

Figure 4 shows the student cohort estimation of their final grade (measured as a course GPA on a 4.0 scale) in the pre-course and post-course questionnaire as well as the overall course GPA.

Figure 4. Pre-Course and Post-Course Student Grade Point Average Estimation and Actual Course GPA.
Discussion and Future Work

The purpose of this paper was to discuss the implementation of state-of-the-art learning tools in Nazarbayev University in the Republic of Kazakhstan and to discuss the impact on student perception of their own learning. The method of implementation of the Virtual Chemical Deposition Laboratory, elevator pitches, and concept tests was discussed.

The evaluation of student learning styles in a student cohort at Nazarbayev University was completed using the Felder-Silverman Index of Learning Styles. This cohort of students had a higher percentage of reflective learners as compared to active learners relative to other studies. This result can be explained by observations from the Rodriguez-Falcon study indicating students from this background tend to be more respectful toward authority figures and therefore may be more inclined to reflect on the information provided them rather than seek out the material to support their own learning needs. It is important for our faculty, then, to understand that our students may depend on us more than we are accustomed to (or perhaps even comfortable with) to direct them on how to learn the course material. It will also be important to incrementally implement active-learning “activities” early in the curriculum so that students can become more comfortable with this learning style.

A higher percentage of the same cohort of students strongly agreed that they learn more from a correct answer than they do from an incorrect answer post-course (32%) as compared to pre-course (19%) whereas a much lower percentage disagreed post-course (13%) compared to pre-course (28%). A significant emphasis was placed on developing a conceptual understanding throughout Engineering Thermodynamics and, given the high percentage of reflective learners in the class, this approach was likely appreciated (at least in terms of learning) because a thorough explanation of the correct answer was given for every concept test implemented in the course.

Case Study 2 indicated a possible significant change in thinking by Student Y from pre-course to post-course regarding learning from a correct answer. The small sample size of very strong “sensors” does not allow for any conclusions to be drawn, but an explanation for the noticeable change by this student regarding this question might be explained by the thoroughness by which each correct answer was explained.²⁰

Qualitatively, the Nazarbayev University Library Knovel database was analyzed for the most commonly searched phrases of 2011. Four of the five most searched phrases were variations of “Low Pressure Chemical Vapor Deposition”, indicating strong student interest in the subject and a desire to participate in their own learning. Therefore, an advanced Virtual Chemical Vapor Deposition experiment was included in Engineering Systems Laboratory in the spring semester of the 2012-13 academic year. Specifically, students were asked to develop a one dimensional model of a multiple-zone chemical vapor deposition reactor and to compare the results predicted
by the model to the (virtual) experimental values. This experiment was included in this course in the hope that student interest in and comfort with the material will allow students to develop their ability to learn without significant input from the laboratory instructor.

The use of “extended” elevator pitches in Engineering in Society offered our non-native English speaking students (most students are, however, quite fluent in English) the opportunity to communicate their engineering proposal in a safe environment. The decision to make the elevator pitches four minutes long (instead of 90 seconds as proposed in the literature) was meant to allow forgiveness in case a student struggled with their delivery in English. After reflecting upon the presentations, it is much more valuable to allow students the opportunity to place their emphasis on the quality of the material to be presented rather than the quantity to be presented. As such, the elevator pitches implemented in the second offering of Engineering in Society will be 90 seconds. Focusing on quality over quantity will be very important in helping students develop their own ability to communicate engineering proposals to a non-technical audience.

The implementation of the Virtual Chemical Deposition Laboratory, elevator pitches, and concept tests into the engineering curriculum all had (or appeared to have) a positive impact on student learning. Two of the tools have been re-introduced into the curriculum and the third (concept tests) will be included in Engineering Thermodynamics next year. These tools will continue to be evaluated with respect to their impact on student learning in this University and optimized (or, in the case of elevator pitches, “un-optimized”) for use in Kazakhstan.

Bibliography

7. *Collaborative Research: Integration of Conceptual Learning Throughout the Core Chemical Engineering*


15. http://jimi.cbee.oregonstate.edu/concept_warehouse/


