Work in Progress: Increasing Student Knowledge Acquisition and Transfer Through the Use of Heuristics in a Team/Lab-Based Protein Engineering Course

Morgan Bocci, J. Robby Sanders and Pedro E. Arce
Department of Chemical Engineering, Tennessee Technological University, Cookeville, Tennessee

Abstract

The Renaissance Foundry pedagogical platform pioneered at the Tennessee Technological University (TTU) Chemical Engineering Department and now integrated in the new engineering model for the College of Engineering at TTU is a rapidly evolving pedagogical platform for improved student learning. The Foundry model incorporates both knowledge acquisition and knowledge transfer paradigms that are integrated through utilization of "resources" towards the development of prototype solutions to problems often required to be identified by student teams[1]. In the protein engineering course reported on herein which has been offered at both the undergraduate and graduate levels, numerous strategies are pursued for increasing both acquisition and transfer outcomes in the students. Teamwork is a critical aspect of the activities in the course in which student teams of chemical engineering students are guided through the process to produce a modified version of a fluorescent protein. Especially in the constraints of a summer semester, the pace of the course is accelerated necessitating the use of focused, hands-on team-based activities, analogies, and other heuristics (i.e. electrophoresis heuristic) to maximize learning in this fast-paced environment. This effort is greatly enhanced through the expert guidance of TA's who have taken the course prior. To facilitate knowledge acquisition of the principles of the polymerase chain reaction (PCR) that is used to modify a DNA base sequence and increase the amount of the target sequence, teams participate in an activity guided by a visual approach of "binding" primers to template DNA and carrying out the steps in each cycle of PCR as described by Chambers et al.[3] This approach allows students the ability to see and understand what is happening in their reaction mixtures of clear fluid. Analogies are used to familiarize students with aspects of molecular biology in which cells are considered to be tiny factories that perform a process to produce a product (the protein). Outcomes associated with the use of these tools will be reported on as will reflections on future directions.

Keywords

Biomolecular engineering, project-based learning, laboratory-based, team-based learning, knowledge acquisition

Introduction, Motivation, and Background

The Renaissance Foundry model, introduced and pioneered by the Chemical Engineering Department at TTU, outlines an efficient and highly versatile protocol for both knowledge acquisition and knowledge transfer in a classroom or a laboratory environment[1]. The goal of the Renaissance Foundry is to be used as "a powerful learning and thinking system to develop 21st century Da Vinci engineers" by incorporating active learning and critical thinking into education across all disciplines[1]. The Foundry model (see Figure 1) is composed of multiple elements across the Knowledge Acquisition Paradigm (KAP) and the Knowledge Transfer Paradigm

(KTP) which are assisted by the facilitator of learning. Per the model, student teams are initially guided to identify a Learning Challenge. This effort is facilitated by utilization of Organizational Tools that are used to either organize/ relate the material to the current student knowledge-base and/ or to focus the search domain for problem identification. The primary tools used in the protein engineering course are the various heuristics utilized. As part of the KAP, the students use resources (facilitator of learning, peers, experts, etc.) to enhance their understanding of the components of the identified challenge to help generate their problem-solving skills. The resources act as the bridge between the two paradigms as they aid in the learning strategies that the facilitator of learning uses in the classroom or laboratory (i.e. guided lectures, integrated lecture-lab approaches, Learning Cycles, and Cycle of Documentation, etc.) designed to help students in acquiring additional knowledge and skills needed to develop a clear understanding of the challenge. The KTP which includes the Linear Engineering Sequence (LES) focuses on the *activities that a team of students* will conduct in order to develop a Prototype of Innovative Technology as the potential solution to the Challenge. It is important for students to have developed a deep enough understanding of the material and the skills needed to effectively implement the LES and reach the Prototype of Innovative Technology and, in general, a constant iteration between the KAP and KTP is expected to reach a successful outcome.

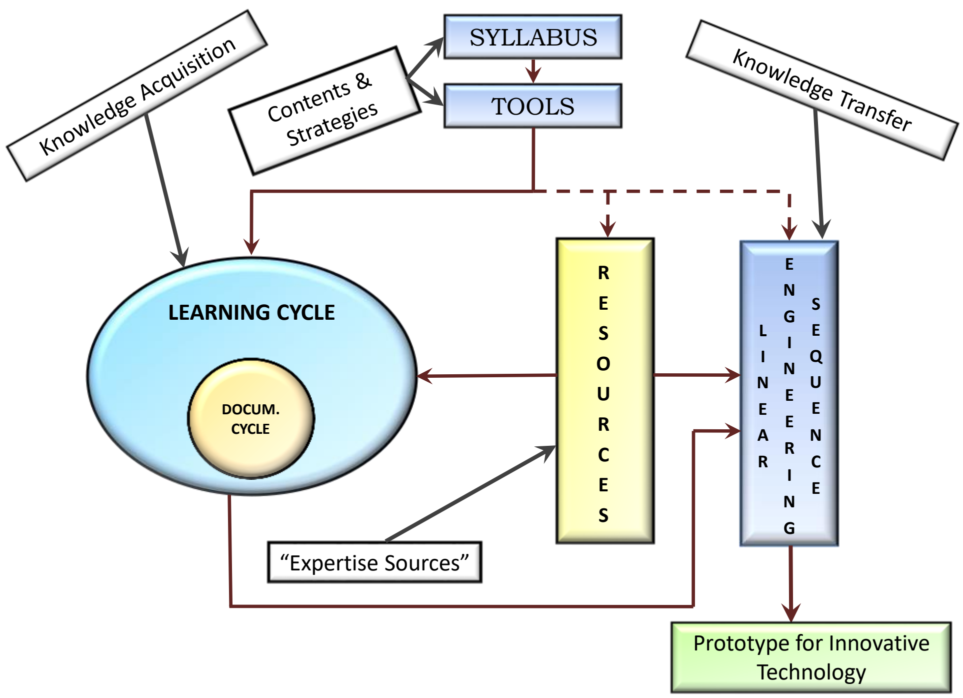

Figure 1. Representation of the Renaissance Foundry Model.

In the course of interest, numerous strategies are pursued for increasing both acquisition and transfer outcomes in the students, with one example of the former being an integration of lab- and problem-based learning as reported on by Rice et al. for an earlier iteration of the course[4]. In these early iterations of the course, a Learning Challenge to develop a modified fluorescent protein is given to the teams. This is followed by a number of hands-on activities with a strong use of teams to develop the necessary laboratory skills needed to modify the fluorescent protein. Additions to the original course developed by Rice were implemented in the summer semester to accommodate for the increased pace. Hands-on team-based activities, analogies, and other heuristics (i.e., electrophoresis model) were incorporated to deepen the understanding of the course material in the accelerated time-line for learning the material. Thus, the efforts focused on knowledge acquisition along with the production of a prototype (a new fluorescent protein).

Foundry Implementation into Protein Engineering—Foundation needed for Knowledge Transfer Paradigm (KTP)

During the development of the original protein engineering course by Rice, laboratory-based class sessions were the main focus and supported by *modified lecture-based class sessions* (including discussions) in order to offer an active learning environment for key concepts used in molecular biology[4]. Active learning as well as collaborative learning (i.e. the use of student teams) are key components of the Foundry and remained the focus of the protein engineering course taught in the summer. The summer course was structured in the same manner with a majority of the class sessions taking place in the lab where teams were exposed to sterile lab techniques and hands-on applications of molecular biology. The modified lecture-based class sessions were, however, the main tool used in the KAP of the Foundry model.

Many students taking the protein engineering course had little-to-no background in biology, so knowledge acquisition played a large role in the desired outcomes of the class. Expert TAs, who had previously taken the course and had research experience in the subject, aided in the facilitation of learning. For a majority of the key concepts learned in the semester, an activity or heuristic was incorporated into the modified class session to aid in the students' ability to gain a deeper understanding of the course material that they would be doing in the lab the next day. As summarized in Table 1 and described further below, these Primary Objects of Knowledge (POK's) are used as building blocks for the students' knowledge moving through the weeks of course material since the material learned each week builds on previous weeks to reach the desired prototype of a new fluorescent protein[2].

Table 1. Heuristics Used to Facilitate Knowledge Acquisition

Heuristic/Activity	Purpose	Desired Outcomes
PCR Simulation	To provide a visual demonstration of the polymerase chain reaction (PCR)	Students complete this activity in a class environment but working by themselves to maximize individual learning that can be leveraged in the team-lab activities.
Analogies	To connect the course content to the chemical engineering discipline	Students are better able to understand how the course material connects to their developing interests and prior knowledge.
Electrophoresis Model	To illustrate the method of separation associated with electrophoresis	Students are better able to interpret results of electrophoresis that is used to extract the information necessary for next steps.

PCR Simulation: To help students understand the fundamental principles of PCR, the students are led through an activity to visually demonstrate what happens in the clear reaction mixture made in the lab. The activity (which occurs in teams sitting around a table but with students working individually) shows the steps for each cycle of PCR by "binding" primers to the DNA template, extending the DNA strand with polymerase (the symbolic role of the student), and then denaturing the double stranded DNA and repeating for the next cycles[3]. This gives the students a tool to help solidify the concepts of the rather abstract and somewhat complicated PCR process. Since PCR is the foundation for engineering a new fluorescent protein, this activity works to help the students acquire the background fundamentals needed in order to understand how to proceed to the prototype development of the proposed challenge.

Analogies: Analogies are used to familiarize students with aspects of molecular biology in which cells are considered to be tiny factories that perform a process to produce a product (the protein). The concept of a "process" is a key aspect of a chemical engineering education. Thus, for a class of chemical engineers with little background in biology, these analogies play a crucial role in the comprehension of the fundamental principles of molecular biology and protein engineering.

Electrophoresis Heuristic: A heuristic was also developed to help explain the general principles of electrophoresis, both DNA gel electrophoresis and polyacrylamide gel electrophoresis (SDS-PAGE). For this demonstration, the students are put into uneven teams (to represent different sizes of DNA or protein) and asked to move through a matrix of hula hoops (held up by the facilitators) in a given amount of time. The hula hoops represent the pores in the gel. As the groups move through the pores, they are not able to move through the next hoop until their entire team is caught up to demonstrate why larger molecules migrate more slowly than the smaller molecules. The students are instructed to move at the same pace and be equally spaced within their groups. They are also instructed to stop in their place when the time keeper calls time. This heuristic was also utilized to show what happens during DNA digestion and how the different bands in an agarose gel which is used to separate DNA are obtained. A modification to this heuristic was also developed in the event that hula hoops are unavailable. In the modified version, "poles" of different lengths (ex. Broom stick, ruler, yard stick, etc.) are held horizontally by each student. A "gel matrix" made of chairs spaced at different widths is set up and the students must move through the "pores" until they reach a pore too small for them to travel through. This modification was designed for a smaller scale demonstration of how gel electrophoresis separates based on size.

Moving Forward

A survey was generated with the goal of gaining an idea of the effectiveness of the course activities for use in future protein engineering courses. Results from the survey will be used to further modify the material and Organizational Tools offered in the course to continue to move toward a more effective adaptation of the Renaissance Foundry. The survey also includes questions which will be given to students who had taken the protein engineering course in previous semesters to gain a better understanding of a more diverse area of possible modifications to incorporate in future courses that would be beneficial.

Along with the survey, the same test was given to the students in a pre-post fashion to gauge their incoming knowledge level and the knowledge they obtained in the course of the semester. Also on the first day of class the students were given laboratory activities to gauge the skillsets of pipette work and accuracy. Throughout the course of the semester, the expert TAs and instructor saw students become more aware and more confident with their abilities in the lab. Each student was required to keep a detailed lab notebook which was their only resource on a lab practical given at the end of the semester. Homework based around the labs and the activities done in the classroom were also incorporated to monitor student understanding of the labs performed each week. Moving forward, these units of assessment can be compared to future classes to determine their effectiveness.

As the course continues to be taught, it can be developed to move into the Knowledge Transfer Paradigm where the students will be able to identify a section of the protein they wish to modify and move through the semester in order to develop their prototype of a new fluorescent protein. Given the lack of biology background in their current classes, this may need to be developed as a two semester course where the students could still have time to acquire enough knowledge to successfully obtain the new protein prototype.

Discussion

Since its development, the Renaissance Foundry model has played a vital role in the way classes are conducted at TTU and, in particular, in the Chemical Engineering Department. Using the course framework developed by Rice et. al[4] and the implementation of the principles described in the Foundry model, the undergraduate Protein Engineering elective has the pedagogical elements necessary (e.g., team based learning, hands-on activities, etc.) to truly impact the way the students learn molecular biology techniques and principles in the context of the chemical engineering discipline.

Further insight into the usefulness of the already incorporated activities and heuristics will aid in the deeper development of this course and lend itself to the possibility of taking the course one step further to truly guide students through the Knowledge Transfer Paradigm where they create a prototype of their own fluorescent protein.

Conclusion

The role of the Renaissance Foundry model in the Protein Engineering course has been identified. As the results from the survey begin to be analyzed further, adaptations to the course framework can be added or removed in order to ensure that the students feel and understand that they are the center of the learning process and to ensure that they are able to move from the Knowledge Acquisition Paradigm to the Knowledge Transfer Paradigm.

Acknowledgements

The authors are grateful to Paige N. Spencer for her collaboration on activities and heuristics used in the course as well as her help in running the laboratory and class sessions for the summer semester.

References

1. Arce, P.; R. Sanders, A Arce-Trigatti, L. Loggins, J. J. Biernacki, M. Geist, J.A. Pascal, and K. Wiant, “The Renaissance Foundry: A Powerful Learning and Thinking System to

Develop 21st Century Da Vinci Engineers," *Critical Conversations: An Interdisciplinary Journal*, 1, 176, (2015)
2. Arce, P. "Principal Objects of Knowledge (POK's) In Colloquial Approach Environments," Proceedings of the 2000 American Society for Engineering Education Annual Conference and Exposition, American Society for Engineering Education, (2000)
3. Chambers, J., C. L. Easter, S.K. Flowers, G. Farkas, "Sequencing a Genome: Inside the Washington University Genome Sequencing Center, Activity Supplement, Paper PCR (DNA Amplification)," Online http://www.nslc.wustl.edu/elgin/genomics/gsc/paperpcr.pdf
4. Rice, J., M. Bocci, and P. Kent, "A Laboratory-Based Approach for an Introduction to Biomolecular Engineering," Proceedings of the 2016 American Society of Engineering Education Southeast Section Conference, (2016)

Morgan L. Bocci

Morgan L. Bocci received her B.S. in Chemical Engineering from Tennessee Technological University in 2015 and is currently working to obtain her M.S. in Chemical Engineering, also from TTU. Her research focuses on the development of protein display technologies for green fluorescent proteins.

J. Robby Sanders

Dr. Robby Sanders is currently an Assistant Professor at Tennessee Technological University in the chemical engineering department. He obtained his Bachelors of Science in Mechanical Engineering from Tennessee Technological University in 1995, and he obtained his Master's degree and his PhD in Biomedical Engineering from Vanderbilt University in 1998 and 2001, respectively. His research interests include biomolecular medicine, including bioassay development, drug delivery and barriers to gene therapy, wound healing, engineering education, and micro-fluidics/lab-on-a-chip applications for clinical diagnostics. Recent courses taught by Dr. Sanders include Transport in Biochemical and Biological Processes, Clinical Immersion at Disciplinary Interfaces, Hemodynamics and Microrheology of Blood Suspensions and Other Biofluids, and Transport Science I: Heat Transfer.

Pedro E. Arce

Dr. Pedro E. Arce is currently a University Distinguished Faculty Fellow-Professor and the Department Chair of the Chemical Engineering Department at Tennessee Technological University. He obtained his Chemical Engineering Degree from the Universidad Nacional del Litoral (UNL), Santa Fe, Argentina, 1977 (minor in heterogeneous catalysis), and his Master's degree and PhD in Chemical Engineering from Purdue University in 1987 and 1990, respectively. His key areas of research included: A- *Nanostructured Materials* and B- *Environmental Catalysis* with applications in health care engineering, energy systems and advanced oxidation technologies. Dr. Arce has a life-interest in *Engineering Education* (collaborative-, creative- and innovation-driven learning; constructionist approaches and transformational approaches to academic organizations). Classes recently taught by Dr. Arce include Physics of Transport-I, Electrokinetic Hydrodynamics, Advanced Kinetics, Transport Science II: Fluid Dynamics, and Team-based Learning (College of Education, TTU).