



Examining the Entrepreneurial Mindset of Senior Chemical Engineering Students as a Result of Exposure to the Epistemic Game "Nephrotex"

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Abstract

Innovation and entrepreneurship are critical to the development and growth of society. Entrepreneurs use innovation to develop novel technologies, while innovation is often supported by the capital raised by entrepreneurs.¹ Companies today are acutely aware of the benefits afforded by employees with entrepreneurial mindsets and have started screening for these characteristics as well as other 21st Century Skills, including problem solving, critical thinking, and communication skills. In a recent article in the *TechCrunch*, a leading technology media property stated, “In our research, we found that some employers are actually looking for students with entrepreneurship experience when hiring for entry-level positions... because students who have an entrepreneurial mindset are accountable for their own actions, aggressive and know how to execute. They also have the communication and sales skills that are necessary to be successful in business today.”²

Recently, several groups have begun research into the characteristics that make up an entrepreneurial mindset. Characteristics including creativity, ability to learn from failure, tenacity, resourcefulness, and strong communication skills have all been documented to be part of this mindset.^{3,4} While these skills include fundamentals taught within engineering programs, they also include skills such as learning from failure that are not often covered as part of the engineering curriculum. One way to teach skills related to the entrepreneurial mindset as well as an appreciation of the product design process is through epistemic games. Epistemic games are computer simulations that provide students the opportunity to think like a professional within a specific field, hence learning to identify with the key characteristics of that profession.^{5,6}

In this research study, the epistemic game Nephrotex was utilized within a senior chemical engineering product design class to develop students’ entrepreneurial mindsets. Our rationale for utilizing Nephrotex was for students to gain an understanding of working within a product design company and the competing opinions that occur as a result of individuals with different focused interests. Nephrotex also provided a scaffolding approach to the design process and did not have just one correct solution, which enabled students to learn from failure during their work. As part of the virtual internship, students were given a human resources intake and exit survey that captured their impressions of their involvement in and viewpoint of entrepreneurship. Analyses performed on the data obtained from these surveys showed some interesting trends. For instance, many of the senior chemical engineering students had little to no involvement with activities related to entrepreneurship leading up to their participation in Nephrotex. Other trends observed were that the chemical engineering student population as a whole was not particularly

confident about its ability to start a business. However, this was shown to shift in the direction of increased confidence after being involved with Nephrotex. We also observed a change in the typology of reasons for wanting to start a business after participation in Nephrotex.

Introduction and Literature Review

Innovation drives society. Every day, phones become smarter, the internet becomes faster, and the world is evolving technologically. Innovation can be thought of as a method which involves creativity to drive a particular thought process or service to be more efficient. As inventive advances are made in a field, the next generation of students learns and builds upon those advances to an even greater extent.

With innovation, however, comes risk. An idea may arise to better a product but may ultimately fail once implemented. Monetary funding frequently supports these advances, and if an idea were to fail, further pursuit may not be an option given possible funding constraints. Entrepreneurs are often the individuals who are willing to take these risks. According to Crumpton, "...entrepreneurship demonstrates the innovation by putting the idea or concept into practical use with the infusion of resources, be it capital or support of institutional leadership."¹ Entrepreneurs need innovation in order to succeed, and innovative ideas needs entrepreneurs in order to progress.

In addition, according to von Hippel, innovative companies can reasonably expect to be more profitable than non-innovative companies.⁷ As companies move towards being even more innovative, individuals that excel in problem solving, critical thinking, and communication skills are desired. These three traits are components of the 21st Century Skills. These skills are specific to content and experience in a particular job field as is stated in the article "Transferable Knowledge and Skills Key to Success in Education and Work...".⁸ The article describes deeper learning as the process in which a person has taken what was learned from a particular situation and applies that knowledge to a new situation. As job fields become more competitive, the push for innovation and deeper learning must be pursued.

To this end, the National Academies, which is comprised of both the National Academies of Sciences and Engineering, the Institute of Medicine, and the National Research Council, call for programs to be implemented that focus on teaching students techniques such as deeper learning. The article goes on to say that, "These programs should feature research-based teaching methods such as using multiple and varied representations of concepts, encouraging elaboration and questioning, engaging learners in challenging tasks while also providing guidance and feedback, teaching with examples and cases, connecting topics to students' lives and interests, and using assessments that monitor students' progress and provide feedback for adjusting teaching and learning strategies."⁸

One method to engage learners while building their 21st Century Skills is through epistemic frame theory. According to Shaffer, epistemic frame theory proposes that each unique profession has its own set of skills, knowledge, values and identities.⁹ One way to provide students with a sense of epistemology is through the use of epistemic games. Epistemic games are computer simulations that allow students to build an idea of the traits needed to work within a specific job field.¹⁰ In epistemic games, students are provided the opportunity to serve in the role of interns for virtual companies that parallel those they may work for after graduation. Through the epistemic game experience students not only learn content that is related to their specific degree path but also develop thinking patterns similar to those of professionals within the field.¹¹ As of recently, David Shaffer's group at the University of Wisconsin-Madison has created an epistemic game in the engineering field known as Nephrotex, where students play the role of an intern for a kidney dialysis membrane company.

As part of Nephrotex, students have to balance internal consultant recommendations with information gained during their individual and team design process. Nephrotex allows the opportunity for students to iterate by gaining feedback on preliminary designs in relation to the requirements given by the internal consultants. This iterative process allows for the generation of new designs and ideas, which are the hallmark of innovation. To support this process, students must build skills related to problem solving, collaboration, and communication, which are attributes linked to the entrepreneurial mindset.¹²

Research Questions

We were interested in understanding whether an epistemic game framework influenced the entrepreneurial mindset of senior chemical engineering students. In order to ascertain whether there was an effect, we approached the study with two principal research questions in mind.

1. Prior to the use of Nephrotex:
 - a. What level of involvement did senior chemical engineering students have with entrepreneurship content?
 - b. How did senior chemical engineering students view entrepreneurship?
2. After completion of Nephrotex, were there any changes in senior chemical engineering students' involvement in and viewpoint of entrepreneurship?

Methods

Nephrotex Epistemic Game Overview

With Nephrotex, students serve as interns for a product design company focused on the development of kidney dialysis membranes. The goal for the students is to design a new kidney dialysis membrane based upon the technical material provided while also meeting recommendations provided to them by internal consultants within the company. During this design process, students are tasked with selecting the design materials, including the membrane material, surfactant, manufacturing method, and carbon nanotube percentages. As part of Nephrotex, students and then student teams can send in preliminary designs for testing to enable

them to get feedback on how their designs are meeting the needs of the internal consultants. This provides a scaffolding element to the process that allows students to learn from the results obtained before selecting a final design. At the end of Nephrotex, teams select a product based upon the testing results and the design they feel best meets the needs of the internal consultants. They then present a poster on their findings to the Nephrotex “executives” for consideration.

Entrepreneurial Mindset Evaluation

In order to examine engineering students’ understanding of business and entrepreneurship, a selection of questions from the Entrepreneurship Knowledge Inventory (EKI) was administered to senior chemical engineering students with permission of the authors of the tool. The EKI is a survey that measures students’ understanding of entrepreneurship in five separate areas. The areas are as follows: Becoming and Being an Entrepreneur, Finance and Accounting, People and Human Resources, Sales and Marketing, and Product Ideation and Development.¹³ Survey questions were inserted directly into the epistemic game as part of the pre- and post-human resources survey that all interns for Nephrotex had to complete. Once both the pre- and post-surveys were completed, a statistical analysis was conducted to examine the effect the epistemic game had on the students’ entrepreneurial mindsets.

Pre and Post Surveys

For our purposes, seven questions were selected from the EKI to examine how students viewed the concept of becoming and being an entrepreneur. The seven questions used were as follows:

1. I belong to an entrepreneurship club or society at my school. (‘No’, ‘I Used to, but not now’, ‘Yes’)
2. I could start a business now if I wanted to. (‘Definitely Not’, ‘Probably Not’, ‘I don’t know’, ‘Probably Yes’, ‘Definitely Yes’)
3. I have a mentor who I consider entrepreneurial. (‘No’, ‘Yes’)
4. I have entered a competition that requires the development of a new product or device. (‘No’, ‘Yes’)
5. I have taken the following number of entrepreneurship/product development courses. (‘Only this course’, ‘One additional course’, ‘Three to four additional courses’)
6. I would like to start a business in order to (select all that apply). (‘Be my Own Boss’, ‘Focus on Markets or problems that interest me’, ‘Focus on technology that interests me’, ‘Have More Flexibility’, ‘Solve a social problem’, ‘Make more money’, ‘Other’)
7. Business ownership outlook. (‘I already own a business’, ‘Would like to own a business within five years’, ‘Would like to own a business within ten years’, ‘No desire to own a business’)

Questions 1, 3, 4 and 5 provided insight into the students’ involvement in or exposure to entrepreneurial-related content, while questions 2, 6, and 7 provided information on students’ current viewpoint on entrepreneurship. Proper human subjects approval was obtained for analysis of the data collected. All student identities were protected through the utilization of numerical identifiers for student work completed as part of the Nephrotex virtual internship.

Statistical Analysis

We obtained responses to both a pre and post survey from 69 senior chemical engineering students participating in Nephrotex. To perform the statistical analysis on the seven questions administered to the students, IBM's statistical analysis software SPSS was used. Depending on the nature of the question and the associated response data, one of several statistical methods was used to examine the impact that Nephrotex may have had on chemical engineering students' entrepreneurial mindsets. For some of the questions, a pre vs. post analysis was done using a paired samples t-test. In addition, since the responses to these questions were ordinal and not continuous in nature, two non-parametric versions of the paired samples t-test, the Wilcoxon and the Sign tests, were also used to corroborate the results. For questions with responses that were nominal in nature, meaning there was no natural ordering of the response data, the McNemar test, which is similar to the chi-square test of independence, was used to assess pre and post differences. The McNemar test, which is used for paired samples, was applied in lieu of the chi-square test since each student was represented twice in the dataset with a pre as well as a post response.

For questions in which the students could select "all that apply," the responses could not be analyzed as matched pairs since the number of pre-game response selections did not necessarily equal the number of post-game response selections. We analyzed these questions using cluster analysis, an analytical technique for identifying groups, or clusters, of students who are similar to each other but different from students in other groups. Cluster analysis is a method for classifying objects, or in our case *students*, into categories. Clustering creates a typology, or a classification scheme, that identifies distinctions among the students based on certain characteristics or ways of responding. Two separate cluster analyses were run – the first using the pre-game responses and the second using the post-game responses. We used the two-step clustering algorithm in SPSS, as discussed in Norusis.¹⁴ A discussion of cluster analysis as well as the other statistical techniques described in this section can be found in the Norusis text.

Results and Discussion

Results obtained from our data analysis in response to the two main research questions are described in this section, including a discussion of statistically-based changes found in the pre and post survey responses.

Senior Chemical Engineering Students Involvement with Entrepreneurial Content – Pre Nephrotex

The EKI seeks to capture students' level of entrepreneurship exposure through the provision of specific questions related to entrepreneurial mentors, number of courses taken, and participation in extra-curricular activities such as competitions and clubs. A summary of the results obtained for the three questions related to this content can be found in Table 1.

Table 1. Summary of Pre-Nephrotex Student Responses to EKI Questions Related to Involvement with Entrepreneurial Content.

EKI Survey Question	Number of Students Responding Yes (%)	Number of Students Responding No (%)
I belong to an Entrepreneurship Club or Society at my School.	1 (1.5%)	68 (98.5%)
I have a Mentor who I consider Entrepreneurial.	17 (25%)	52 (75%)
I have entered a competition that requires the development of a new product or device.	9 (13%)	60 (87%)

Students were also asked about the number of entrepreneurial classes they had taken prior to the virtual internship. In response to this question, 61 students (88%) responded that the only class they had taken was the current one, which involved the epistemic game Nephrotex. Seven students (10%) replied that they had taken one additional course, and one student (2%) claimed three to four additional courses. It is apparent that the majority of the students had *not* taken any entrepreneurial-based courses besides the current class.

Therefore, while the four questions varied in their distribution of responses, it is evident that the majority of the students had very minimal previous involvement with or exposure to entrepreneurial content prior to the implementation of the epistemic game Nephrotex.

Senior Chemical Engineering Student’s View on Entrepreneurship- Pre Nephrotex

In an effort to determine viewpoints on entrepreneurship prior to participation in Nephrotex, EKI survey questions pertaining to their ability and desire to start a business as well as the timeframe for following through on this initiative were asked. Table 2 summarizes the results that were obtained from students on their viewpoints of entrepreneurship.

Table 2. Summary of Pre-Nephrotex Student Responses to EKI Questions Related to Student’s View on Entrepreneurship.

EKI Survey Question	Number of Students Responding (%)				
	Definitely Not	Probably Not	I Don’t Know	Probably Yes	Definitely Yes
I could start a business now if I wanted to	11 (16%)	24 (35%)	20 (29%)	10 (14%)	4 (6%)
	Number of Students Responding (%)				
	Never	Within 10 years	Within 5 years	I already own a business	
I would like to own my own business	41 (59%)	20 (29%)	7 (10%)	1 (2%)	

Of the 69 students, the large majority (80%) believed that they could *not* start a business or were not sure whether they could start a business at that time. However, 20% believed they probably or definitely could start a business. This result is not particularly surprising as students within this mid-Atlantic university are not exposed to course content related to entrepreneurship as part

of their degree program. Students were also asked about possible timeframes on starting a business. Approximately 40% wanted to own a business (if they did not already so) within the next 10 years prior to their involvement with Nephrotex.

Students were subsequently asked if they were to start a business, why they would want to do so. Students were allowed to select all of the responses that they felt applied to them. The two most common responses were “Focus on technology that interests me” (52 responses) and “Focus on problems or markets that interest me” (46 responses). Many students also selected that they would like to start a business in order to “Be my own boss,” (41) “Have more flexibility,” (41) and “Make more money.”(39) It was apparent that before the virtual internship, students wanted to start a business based primarily on their technology and market interests.

Changes in Senior Chemical Engineering Students' Involvement in and Viewpoint of Entrepreneurship after Completion of Nephrotex

Immediately following the completion of the virtual internship, students were asked to answer the same EKI questions posed prior to Nephrotex. A statistical analysis was then conducted to determine if there were any changes in the entrepreneurial mindset of the chemical engineering students.

The first analysis examined whether there was any change in students' involvement with entrepreneurship content as a result of the epistemic game. In analyzing results from the questions related to involvement in an entrepreneurship club or society, participation in a business competition, and the number of entrepreneurship courses taken, there were no significant changes found pre to post game. This is not surprising considering the relatively short implementation timeframe for Nephrotex (ten weeks within a single semester).

Analysis of the question “I have a mentor who I consider entrepreneurial” showed an increase in the number of “yes” responses from 17 to 24 after participation in Nephrotex. This change may be attributed to the entrepreneurial characteristics of the course instructor, who has launched several of his own ventures. However, using the McNemar test, we were *not* able to conclude a statistically significant difference pre to post-game in student belief about having an entrepreneurial mentor ($p=0.092$).

Overall, the post-analysis performed on senior chemical engineering students' involvement with and exposure to entrepreneurship content showed no statistically significant differences after implementation of Nephrotex, which is not entirely unexpected.

Subsequently, we examined whether participation in Nephrotex was associated with changes in students' entrepreneurial viewpoints. Analysis of the question related to students' viewpoints on business ownership within a certain timeframe showed little change pre to post game, which was also not significant based upon the McNemar test ($p=0.57$).

However, based on a paired samples t-test, we were able to find a significant difference pre to post game in student attitude about ability to start a business ($p=0.009$), as shown in Figure 1. The change was in the direction away from “no” and towards “yes,” where our ordinal scale

extended from definitely not (1) to definitely yes (5). Given that the data used were ordinal, we also ran the non-parametric version for paired samples - the Wilcoxon Signed Ranks test - to corroborate the results. We verified that the differences were a sample from a symmetric distribution, a required assumption for this test. The results from this test were consistent with those from the t-test, indicating that there was a significant



Figure 1: Pre and Post-Survey Responses for Capabilities of Starting a Business Now. Numbers in the figure represent the number of students that selected each response.

difference pre to post ($p=0.010$). Taking the analysis one step further, we ran a second non-parametric test for related samples – the Sign test. For this test, the p-value was 0.052;

however, this test has less power than the Wilcoxon test to detect true differences when they exist. Based on the aggregate results from these three tests, we concluded a significant difference (pre to post game) in students’ attitude about their ability to start a business now, with a shift towards ability to start a business post game play. We believe that this difference may be attributed to a combination of exposure to an entrepreneurial mentor (instructor for this course) as well as participation in Nephrotex. Gaining exposure to the different elements involved in the design of a product from concept to final product proposal within Nephrotex can provide students with a better understanding for how companies operate and move products from concept to production.

For the question “I would like to start a business in order to (select all that apply),” there was some fluctuation in the responses pre to post game. We conducted a pre and post cluster analysis to investigate any changes in the typology, or student groupings, based upon their reasons for wanting to start a business. Table 3 shows the pre and post-game clusters that formed as well as the student membership in each of the clusters. For example, there were 17 students in pre-game cluster #2. Of these, 10 were in post cluster #1, 4 were in post cluster #2, and 3 were in the post outlier cluster.

Table 3: Description of Clusters: Reasons for Wanting to Start a Business

Pre vs. Post-Game Clusters of Reasons for Wanting to Start a Business: Student Distribution			POST-game Clusters			Total
			1	2	3	
	Cluster #	Cluster Description	Designers with personal interests	Designers with social and personal interests	Outlier	
PRE-game Clusters	1	Designers with moderate social interests	2	2	8	12
	2	Designers with personal interests	10	4	3	17
	3	Designers with social and personal interests	1	13	5	19
	4	Outlier	4	4	13	21
Total			17	23	29	69

When clustering the pre-game responses, four clusters (i.e., student groups) formed, including an outlier cluster, as shown in Table 3. In order to maximize the quality of the clusters, outlier handling was used to place (within an outlier cluster) those students who did not fit well with the others.¹⁴ For the pre-game clustering, 21 students formed the outlier cluster, while 29 students comprised the outlier cluster in the post-game analysis.

Based upon the characteristics or response choices of the students who are grouped into each cluster, the clusters can be named or described. The first pre-game cluster, which is described as designers with moderate social interests, was characterized by students who wanted to start a business so they could focus on their *design interests* related to certain markets and technologies, with little concern for traditional or personal employment-type issues such as flexibility, supervision, or greater money. This group, however, showed a moderate level of concern for solving social problems. We defined a characteristic as having a “moderate” level if it applied to 60-79% of the students in the cluster and “large” if it applied to 80-99%. The second pre-game cluster differed in that the students wanted to obtain more of the personal benefits of flexibility and greater money; in addition, this group for the most part was *not* motivated by social concerns. The third pre-game cluster differed from the second in that all the students had a social outlook, in addition to interests in personal benefits and the opportunity to design with certain markets and technologies.

In contrast, just two “named” clusters emerged with the post-game responses. The two post-game clusters differed in the social outlook of the students. In post-game cluster #1, none of the students were interested in solving social problems and were motivated by their areas of interest and personal-type issues. In post-game cluster #2, all the students had a social outlook in addition to being motivated by *designing* in certain markets and technologies and achieving personal benefits. Based upon these differences in the pre vs. post-game cluster solutions, there was a pre to post-game change in the typology, or student groupings, relative to reasons for wanting to start a business, suggesting an impact by the game on this aspect of the entrepreneurial mindset. It is hypothesized that Nephrotex may have influenced this change due to its focus on multiple perspectives invested in the design of a hemodialysis device. Unlike some engineering design projects, Nephrotex has students balancing the input of internal stakeholders who all have different priorities and requirements of the final design. This may influence students to see beyond the traditional engineering requirements of a design towards the potential social implications of the work that they are performing.

There are measures for quantifying the “goodness” or quality of a cluster solution, such as the silhouette coefficient. This coefficient ranges from -1 to +1, with -1 being most undesirable and +1 being most desirable. For the pre-game cluster solution, the silhouette coefficient was approximately 0.45, indicating fair, but nearly good, cluster solution quality. SPSS identifies cluster solution quality as ranging from poor to good, with good extending from 0.50 to 1.00. For a further description of this, please refer to the Norusis reference mentioned previously.¹⁴ In contrast, using the post-game responses, only three clusters, including an outlier cluster, were formed. For the post-game clustering, the solution quality was good, with a silhouette coefficient of approximately 0.60.

For the pre-game clusters, the response choices related to starting a business that were most important were the following: increased flexibility, being one's own boss, and social concerns. This was determined by examining the predictor importance scores for the response choices, as discussed in Norusis.¹⁴ Each of the importance scores for these three answer choices was above 0.8, with the scale in SPSS ranging from 0.0 to 1.0. The next-highest response choice score was approximately 0.5. In contrast, for the post-game clusters, *social concerns* was by far the most important variable in forming the clusters and distinguishing the students. Its importance score was 1.0, with the next highest score at less than 0.2. Thus, our cluster analyses showed differences pre to post game related to reasons for wanting to start a business. Based upon all the various differences in the pre vs. post-game cluster solutions, it appears there is some preliminary evidence that Nephrotex can have an impact on the reasons for wanting to start a business.

Conclusion

This study has provided initial evidence that Nephrotex can be influential in changing students' entrepreneurial viewpoints or mindsets. For example, with the question "I could start a business now if I wanted to," we saw a statistically significant change towards more positive responses, aligning with higher confidence in their ability to start a business. Using cluster analysis, we also found a change in the typology or student groupings based upon their reasons for wanting to start a business. This change brought about a higher awareness of the categorization of students who wanted to start a business, with a distinction between those students motivated to do so based upon social concerns or the lack thereof.

As students enroll in engineering programs at colleges and universities, it is important to build an entrepreneurial mindset. Building the entrepreneurial mindset through epistemic games can help in shaping the 21st Century skills, which are so important in engineers' professional careers. As students develop and strengthen these skills, there is much more opportunity for entrepreneurship and innovation to occur. This will be a key for college students who seek to set themselves apart from others when seeking employment.

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