

LEARNING THROUGH SIMULATION

Student Engagement

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The use of simulations in chemical engineering undergraduate degree courses has increased rapidly in recent years. It has reached the point where simulation packages form the basis for a number of chemical engineering textbooks (*e.g.*, Seider, *et al.*^[1] and Svrcek, *et al.*^[2]).

The emphasis of most of the simulations in chemical engineering education seems to be on teaching students how to use simulations to solve typical engineering problems.^[3] We have found little evidence of simulations being explicitly used to develop conceptual understanding, and we therefore sought to investigate their potential use in this regard. In order to create a context where this investigation might take place, we used the variation theory of learning to redesign a distillation column simulation undertaken by junior students.^[4]

This paper is a follow-up to our previous study and concerns examination of how effectively students engaged with a distillation column simulation, with a view to determining conditions that were conducive to learning through the simulation. Clearly, a better understanding of what features of simulations facilitate student learning, as well as how students engage with such exercises, will mean that simulations could be used more effectively to promote learning.

In this study junior chemical engineering students at the University of Cape Town (UCT) carried out a distillation simulation. Distillation is a challenging part of the curriculum and students need to understand the interaction of a number of different parameters, such as feed-tray location, multiple components, side-stream draws, and integration of mass and energy balances.^[5] At the time of the study, the students

were nearly at the end of a course on mass transfer and had completed the section on distillation and written a test on it. They had also done a project in the course using the ChemSep simulation package as a design tool. Note that in this course, as in many others in our program, lectures are supplemented by weekly tutorials.[†]

In this paper we will first examine simulations as a learning tool and then deal with some theories of learning which we found helpful in framing this study. Next, we will present the development of the simulation exercise that was used and the experimental approach we used to analyze what was hap-

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[†] Tutorials are two- to three-hour in-class problem-solving sessions in which students work on a set of problems, whether individually or in small groups, and submit their solutions; satisfactory performance in these submissions is normally a prerequisite for being allowed to write the examination in the course.

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pening as the students undertook the exercise. Finally, we will discuss the findings of the study and draw conclusions about how better to use simulations for learning in chemical engineering courses.

SIMULATIONS AS A LEARNING TOOL

Due to the growth in computer technology, simulations are being used abundantly in education, particularly in science and engineering. The majority of respondents to a survey conducted by Dahm, *et al.*^[3] recognized simulations as “a tool that graduating chemical engineers should be familiar with . . . taught for its own sake.” This dominant view among engineering educators of simulations as engineering tools underplays the value they can have from an educational perspective. Some researchers, however, point to the educational benefits of simulations. For example, Goodyear^[6] argues that simulations allow students to understand complex devices that may not even be understood through direct contact with the equipment itself. Kassim and Cadbury^[7] note that simulations should support and reinforce a student’s independence, in turn promoting self-directed study — a fundamental requirement for a successful university education. Davies^[8] suggests that simulations offer the additional benefit of allowing students to experience ownership of the task once they engage with it, which encourages intrinsic motivation.

Goodyear identified four potentially problematic areas in simulation-based learning

- *Inadequate knowledge of the software package*
- *Lack of investigative or problem-solving skills*
- *No understanding of the benefits of simulations as learning tools*

TABLE 1
Features that Facilitate Simulation Learning

- Simulations seen as a learning tool
- Complexity approaching reality
- Peer-interaction learning environment
- Thorough accompanying instructions
- Use of a familiar package
- Sufficient time for engagement to occur
- Learning history
- Open-endedness

TABLE 2
Simulation Learning Foci

- A** Simulations as a *given assignment* that needs to be completed
- B** Simulations as tasks that are a *representation of the phenomenon*
- C** *Manipulation of the simulation* to understand how the simulation itself works
- D** *Exploration of the phenomenon*, where students engage and use it to predict results

- *Inability to transfer knowledge gained from simulations to other areas*

A key finding emerging from this is that students need to be aware of the learning possibilities that a simulation presents. It is important to consider this feature in simulation design. Other critical features emerge from a range of studies reviewed below.

In a case study on a heat transfer simulation, Davies focused on trying to better understand the simulation characteristics that facilitate improved understanding and learning. Davies showed that the following key features are necessary to support student engagement with simulations:

- *Complexity of the simulation approaching that of reality*
- *Learning environment allowing peer interaction*
- *Thorough set of accompanying instructions*
- *Overcoming navigational uncertainty by using a familiar package*
- *Significant time for engagement to develop*

This study also highlights the need for educators to design simulations with *learning* as the primary objective, as opposed to simply reproducing a scenario or solving a problem.

Parush, *et al.*,^[9] identified that the presence of a *learning history*, which allows students to stop, rewind, or restart the simulation at any point, resulted in better understanding and also in better long-term retention of knowledge.

Strijbos, *et al.*,^[10] explored an additional feature, where the simulation learning objective is “open skills,” such as argumentation and negotiation, that arise when students build on each other’s knowledge. *Open-ended* tasks promote better interactive discussions due to the presence of a number of possible solutions.

From this short review, the features listed in Table 1 have been identified as facilitating effective learning through computer simulations. In this study we will examine the effectiveness of each of these features in promoting simulation-based learning.

In one of the few studies that has looked at simulation-based learning from an educational research perspective, Ingerman, *et al.*,^[11] recognized four ways in which students focus on simulations. They are listed in Table 2. We will use the term *interaction* to signify a situation where students are merely manipulating the simulation to perform tasks without thinking, and the term *engagement* to indicate where students attempt to understand what is happening in the simulation. Using this terminology, we consider foci A and B to be indicative of *interaction* with the simulation, while foci C and D show *engagement* with the concepts the simulation presents.

LEARNING THEORY

There are many learning theories that attempt to address how we learn. Phenomenography focuses on the student ex-

Simulations need to be introduced to students as learning tools from early in the program, before they begin working with them Simulation tasks must encourage exploration, but also provide sufficient guidance to help students focus on the key variables necessary for conceptual understanding.

perience of learning and encompasses research that has been done on students' approaches to learning, as well as that which has focused on how learning is facilitated through variation.^[12]

Deep and surface approaches to learning were first identified in a study by Marton and Säljö,^[13] and subsequently confirmed in many other studies. A more recent study by Case and Marshall^[14] identified two further approaches to learning that expanded the typology to include the following four approaches:

- *Surface approach*: student focus is on gathering and memorizing information
- *Procedural surface approach*: the focus lies on memorizing algorithms or solutions to problems in order to pass a test
- *Procedural deep approach*: students link formulae and algorithms together with the aim of eventually understanding concepts through repetitive applications
- *Deep approach*: here the students' focus is on developing conceptual understanding

It is important to carefully distinguish between the two procedural approaches. In the procedural surface approach, students are simply using algorithms without any underlying attempt to think about concepts. In the procedural deep approach, standard solution algorithms are coupled with evidence of applying some thought to understanding the problem.

Case and Marshall^[14] have shown that these approaches are not fixed, but rather depend on factors such as students' perceptions of the course context and their previous learning experiences. An important finding of their research is that courses taught using a procedural approach may not succeed in students developing a deep conceptual understanding. This has implications for the work presented in this paper since distillation is traditionally taught procedurally, with the focus on solving problems mathematically.

With regard to learning through variation, Marton and Booth point out that learning consists of different aspects of a phenomenon being concurrently discerned and present in a person's focal awareness (when something is noticed in a new way, or brought into the foreground, it comes into focal awareness).^[12] Variation is posited as central to such discernment. There are many examples of applying these concepts at the lower school levels, but only a few we are aware of at

the university level, two of which are in engineering.^[4,15]

We consider the four simulation foci presented in the previous section to be closely related to these four approaches to learning, as shown in Table 3. Note that the first two approaches/foci are characterized by the intention of passing the test or interaction with the simulation, whereas the last two approaches/foci

are characterized by the intention of understanding or engaging with the simulation.

DEVELOPING THE SIMULATION EXERCISE

The primary focus of this work was to answer the following questions:

- *How do these students view simulations?*
- *Was learning achieved during the simulation?*
- *How did students engage with the simulation?*
- *How can the benefits of simulation-based learning be maximized?*

The simulation exercise was set up with these questions in mind.

We also needed to take into account the traditional approach taken to the teaching of chemical engineering in most of our program, which emphasizes a procedural approach, with class exercises and tutorials consisting of solving standard textbook problems that require a numerical solution rather than explanations. The teaching of distillation in the mass transfer course the students were doing at the time they undertook the simulation exercise tended to follow this general pattern.

In the simulation exercise, the impacts of feed vapor fraction, feed ratio, side-stream draw, and additional components on the optimum feed-tray location were explored in the tasks that the students performed.

The Simulation Exercise

Before beginning the simulation, students were informed of the nature of this research, which was to understand how

TABLE 3
Approaches to Learning and Simulation Foci

<i>Passing the Test / Interaction</i>		
<u>Approach</u>	<u>Simulation Focus</u>	<u>Strategy</u>
Surface approach	Following the task	Memorizing
Procedural surface approach	Simulation as representations	Problem solving
<i>Understanding / Engagement</i>		
<u>Approach</u>	<u>Simulation Focus</u>	<u>Strategy</u>
Procedural deep approach	Manipulation of simulations	Problem solving
Deep approach	Exploration of phenomenon	Concepts

TABLE 4
Simulation Exercise

- 1) For the given benzene-toluene distillation column:
- a) The feed vapor fraction is changed from 0.5 to 0 and to 1. Identify and explain four effects that this has on the system, using a simulation history.
- If the vapor fraction changes, is the feed location still optimum? Why or why not? If not, in each case optimize the feed location in the system.
- It is desired that the distillate has a purity ≥ 0.95 benzene. What is the best vapor fraction to run this column at: 0, 0.5, or 1? Explain your reasoning.
- b) What is the effect on the feed location if the benzene and toluene flowrates were changed to the specified values?
- c) It is desired to draw a liquid side stream (0.2 kmol/s) with approximately 60 mol% benzene. On which stage would you draw this stream? Can you explain the effects this draw has on the system? Does this affect the feed location? If so, find the optimum location.
- If the side stream's phase were to change to vapor, would the feed location still be optimum, and why?
- 2) For the given n-butane - n-hexane distillation column:
- a) Examine the system that is given to you and note any important results or graphs that may be required for comparisons in the rest of Task 2.
- b) Add n-pentane to the system (flowrates specified).
- What are the effects of the additional component on the system? Can you explain the effects? Has the additional component affected the feed location at all?
- c) By changing the feed location up one or down one tray, can you get a similar McCabe-Thiele diagram? What parameters would you analyze to decide which is the optimum feed location and what features should they display, *i.e.*, high value, low value?
- d) It is desired that n-butane in the distillate be approximately 91%. Optimize the system to meet this specification. What are the new specifications and why have you chosen them?

students learn through simulations. The aim of this was to encourage students to associate learning with the exercises.

ChemSep, an educational package that specifically models separations, is the only simulation package that UCT chemical engineering students have been exposed to by the end of their junior year. They had used it as an engineering tool in a number of class exercises and tutorials, as well as in the junior design project, and were thus familiar with it. This package was thus used to ensure that navigational uncertainty had been overcome. It treats the column as a black box in terms of calculations but allows the user to view all the column profiles. A drawback of ChemSep is that it does not have a learning history function. A more sophisticated package, such as AspenPlus, could have been used, but then navigational uncertainty would have been a major hindrance. Consequently, students were encouraged to create a physical learning history by recording necessary data and diagrams in a Word or Excel document.

In order to bring the concept of feed-tray location into the students' focal awareness, its location had to be discerned by not always appearing optimum on the McCabe-Thiele diagram. This proved to be the largest hurdle in the simulation setup. ChemSep automatically optimizes the system and treats the feed-tray location and number of stages as fixed values, adjusting the reflux ratio to meet the purity specifications. Consequently, the feed-tray location always appears optimum on the diagram. By keeping the reflux ratio constant, the feed-tray location would no longer appear optimum and could therefore be discerned. This compromise between complexity and variation of the key concept resulted in a simulation that did not present the best column operation, but was essential to facilitate learning.

The simulation consisted of two tasks (see Table 4 for full details). The first task consisted of a benzene-toluene system and focused on the impacts that feed-vapor fraction, feed ratio, and side-stream draw have on optimum feed-tray location. This was to sensitize the students to look at the variables they would need to solve the second task consisting of an n-butane - n-hexane system, to which n-pentane was added.

Since the objective of the exercise was to observe how students engage with simulations, not their ability to set up a system, both simulation tasks were ready for the students to run and all information was supplied on the simulation task sheet. The simulation was performed in pairs to facilitate peer interaction. Thorough instructions were provided to the students to encourage them to explore the system in each task.

Table 5 indicates how closely we were able to approach the characteristics of the "ideal" simulation in this study. The aspects that were not achieved were complexity approaching reality (due to the choice of simulation package) and significant time for engagement (due to the timing of the research coinciding with the approach of final examinations).

TABLE 5
How Closely Did We Achieve the Features Facilitating Simulation Learning?

<u>Feature</u>	<u>Incorporated in Design?</u>
Simulations seen as a learning tool	yes
Complexity approaching reality	no
Peer-interaction learning environment	yes
Thorough accompanying instructions	yes
Using a familiar package	yes
Sufficient time for engagement	no
Learning history	Physical, not automatic
Open-endedness	yes

The Conceptual Test

The conceptual test was developed to gauge students' understanding of distillation before they undertook the simulation exercise (the pre-test), as well as to gauge any improvement in understanding after the simulation exercise (the post-test).

Both the simulation and the conceptual test questions were structured so the students needed more than their theoretical and procedural knowledge base to explain their answers. Table 6 shows a typical question in the conceptual test.

The conceptual test consisted of five questions, four of which were multiple choice. Each question focused on one of the above four variables that have an impact on the distillation system. It was also intended that the conceptual test prepare the students for the simulation tasks by bringing the concept of feed-tray location into their focal awareness. All the multiple-choice questions required the students to explain their answers.

The conceptual pre- and post-tests were evaluated according to the framework laid out in Table 7, where an example of each type of approach is given. A model answer for the question illustrated in Table 6 should take the form of: "Decreases. More vapor is entering the column and consequently there is less need to reboil. The additional energy has entered the column with the feed."

Note that considerable judgment is needed in categorizing qualitative responses, because they are not purely right or wrong. While Derek's answer in Table 7 is in fact incorrect, it was at least indicative of an attempt to think about what was happening, and so was classified as indicating a procedural deep approach, compared to Delia's solution which seemed to result from the use of an algorithm. Note that all names used here are pseudonyms.

EXPERIMENTAL APPROACH

Beveridge (cited in Flyvbjerg^[16]) stated that in social science "more discoveries have arisen from detailed observations than from statistics applied to large groups." This suggests that an in-depth study of a small, purposeful group of students undertaking the simulation exercise, as opposed to a larger, statistically representative sample, would provide rich data to enable us to answer the questions posed in this re-

search. The research sample was therefore composed of seven students from a range of academic and social backgrounds, each of whom selected a partner of his or her choice.

Methods of Data Collection

A summary of the data collection process is shown in Figure 1. Two one-hour sessions were scheduled with each student pair. In the first session the conceptual pre-test and the simulation exercise were performed. The second session consisted of the conceptual post-test and an interview. An hour was needed for each of the sessions, which were held in the final two weeks of term. Two separate sessions were needed to establish the extent to which any learning that occurred was retained. In addition to the pre- and post-tests, a range of other data was collected, consisting of screen capture of the simulation, field observations, and interviews, as detailed below.

Each pair's interaction during the *simulation* was videotaped and their mouse and keyboard movement captured using Camtasia screen-capture software. A few students were initially nervous at the mention of its use. An isolated room was used for both sessions to minimize intimidating factors.

Field observations were recorded during the simulation exercise. Comments on each pair's interaction with each other and the simulation, as well as the extent of their engagement, were made. Body language such as students leaning toward or touching the screen, or taking over control of the mouse, was a primary gauge for interaction. Video and field data were fundamental for analyzing engagement. The video camera and our presence could not be avoided without a special laboratory where students could be observed

TABLE 6
Typical Conceptual Test Question (1b)

Assume a 50% benzene, 50% toluene stream at its bubble point is fed to a column. The column has 10 stages and you can assume a constant reflux ratio. Feed enters the column on stage 5. At present, the distillate composition is 95 mol% and the bottoms composition is 5 mol% benzene. If the feed stream were to change and be fed at its dewpoint what effect will this have on the following? (You should answer without using a McCabe-Thiele diagram.)

Reboiler duty:

A-Increases B-Decreases C-Stays the same D-Cannot say

Please explain your reasoning.

TABLE 7
Examples of Responses (for Question 1b from Table 6)

<u>Value</u>	<u>Description</u>	<u>Illustration</u>
0	Incorrect	(Increases due to) "increased vapor in system" –Vani
1	Surface Approach	"Decreases due to decrease in flow of both species to the bottom of the column" –Gershwin
2	Procedural Surface Approach	"More vapor is introduced to the system" –Delia
3	Procedural Deep Approach	"Less number of stages in the bottom of the column, thus less vapor is required to reach the feed stage" –Derek
4	Deep Approach	"Vapor is being supplemented by the feed, so less of it has to be vaporized." –Mpho

through one-way glass.

Interviews were conducted with students to determine if the simulation exercise had been successful in bringing the concept of feed-tray location into their focal awareness and further, to establish how students view simulations and their engagement with them. Stimulated recall^[17] was used in each interview, where video and screen capture clips of the pair performing the simulation were played back to them for further probing and clarification of some of their comments and actions during the simulation. The interviews were conducted in pairs, audiotaped, and transcribed for further analysis.

A senior year *focus group* of seven students was used to further explore some of the findings and tentative conclusions of this research. This was also to establish whether these findings were isolated to the mass transfer course, or a more general experience in the degree.

RESEARCH FINDINGS

In this section each of the four questions that framed this study will be addressed in turn.

How Did These Students View Simulations?

From their general classroom experience of simulations, only three of the 14 students held a positive view of simulations, as far as learning was concerned. The majority of students saw simulations as “plug and chug” tools that merely save calculation time, despite having been sensitized to associate the exercise with learning. This result was even more disturbing when it emerged that students held a positive view of simulations only as a timesaving tool and felt that they were only being used properly when generating “reasonable” answers.

In the interviews, each student pair was asked to describe their approach to the distillation simulation that they had completed. Their answers were categorized in terms of the focus levels identified by Ingerman, *et al.*,^[11] as described earlier (Table 2). The results are shown in Table 8.

It was hoped that students would demonstrate learning foci at the levels of simulation as representations and manipulation of the simulation. In this case, however, a number of students adopted the weakest focus — simply following the task.

Students were also asked to discuss how their approach would change if they were doing the distillation exercise in a normal three-hour class tutorial session. The majority of them did not expect that their focus would change. This again emphasizes how they view simulations in the same light as tutorials. Both junior and senior students saw tutorials as necessary primarily for meeting minimum course requirements for entrance into the final examination, which results in the learning potential of simulations being seriously reduced.

The two pairs that manifested the deepest focus level found in this study, namely “manipulation of the simulation,” both felt that their focus would weaken in a tutorial environment. One of the pairs felt that tutorials were only worked until boredom overcame them and then they became a social event, while the other pair found tutorials pressurized and indicated that they would focus on simply getting the task done on time. They added that much of the understanding that can be developed through this type of exercise gets lost in the rush to ensure that minimum requirements are met.

Was Learning Achieved During the Simulation?

Each student’s progression in approach was analyzed, as

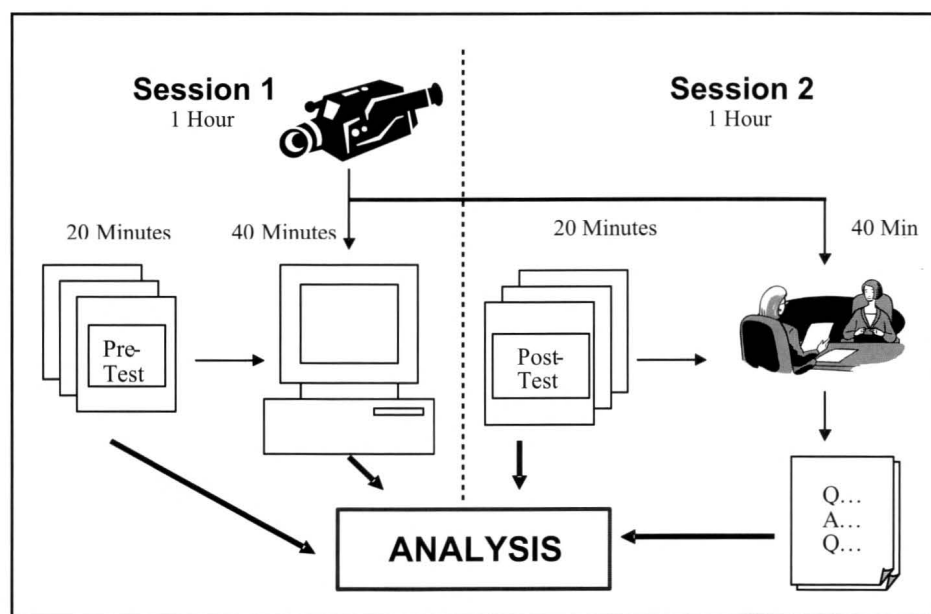


Figure 1. Data collection process.

<i>Focus</i>	<i>Description</i>	<i>Occurrence</i>
A	Following the task	2
B	Simulations as a representation	3
C	Manipulation of the simulation	2
D	Exploration of the phenomenon	0

shown in Table 9. A student was assigned a score on the post-test. The scoring was as follows: A score of -1 was assigned if their approach regressed, a 0 if their approach remained the same, and a $+1$ if their approach progressed from the pre-test. The progressions and regressions were tallied and appear in Table 9. We have also identified those students who said they enjoyed the task (represented by the gray block), which is discussed in the following section.

The results of all questions showed that half the students did not improve in approach, despite a potential to do so, as indicated by negative scores in the overall improvement column. An inherent implication of this is that despite the “close-to-ideal” simulation environment, the exercise did not result in significant conceptual development. This is potentially due to students’ preoccupation with their upcoming exams. The fact that half of the students did learn and develop conceptually from the exercise is encouraging, however.

As depicted in the table, some students regressed from their original approach. Many previously demonstrated a deep conceptual approach in the pre-test. Some post-test comments indicated boredom, after students had circled the correct answer.

Very little exploration of the concepts was observed. This result was confirmed by the focus group held with senior students, who all felt that their approach to tutorials (including simulations) was merely to complete the task as quickly as possible.

How Did Students Engage With the Simulation?

All seven pairs *interacted* with the simulation, whether focusing on understanding or simply going through the motions. Despite the obvious interaction observed, we found that *engagement* generally did not occur.

A definite correlation between enjoyment and engagement was noted during this work. All students who expressed enjoyment of the simulation exercise experienced an overall progression in their conceptual understanding (gray block in Table 9). Bongani’s enjoyment is evident below:

Bongani: “*But even in the literature, like when [the lecturer] teaches us to use ChemSep, all those things, but you don’t go into detail, like what effects this has on this. The problem is just given to you and you have to solve this thing . . . we never have a chance of investigating.*”

This student clearly appreciates the advantages of simulation-based learning and showed an overall progression in his approach from the pre-test. Nearly all students who expressed partial or no enjoyment regressed in their approach, except for Arkash and Thandiwe.

The group of seniors confirmed that a correlation between learning and enjoyment does exist. Furthermore, they felt that enjoyment results from small subtasks of an exercise

being accomplished. They felt that understanding the reasons for using simulations and enjoyable exercises is necessary for the tasks to be meaningful.

Students generally did not explore the simulation beyond the tasks laid out in the exercise. They focused on generating results and the majority did not use these results to explain the observed effects, despite being asked for conceptual explanations of what they saw in each question. This highlights a need for students to be sensitized to a new way of learning when presented with one.

Only five students felt they had not learned about the concept they believed the simulation focused on. The focus of the students who did not feel they gained a deeper understanding generally lay on merely changing numbers.

The video equipment was not problematic and students generally were not hindered by this factor. External factors such as mood and attitudes were found to hinder five students. Previous experiences with ChemSep hindered learning in one student.

Students’ procedural approach was generally a hindrance to their development of conceptual understanding. Many students expected to be able to answer all the questions corresponding to the common engineering tutorial focus, where the aim is to complete tasks quickly and correctly. This emphasizes that students do not see the learning value of simulation exercises, but see them as a test of what they already know.

How Can the Benefit of Simulations Be Maximized?

The success of the features identified as facilitating learning through engagement with simulations will be assessed in turn.

Simulations as learning • It is evident from this study that it takes more than the effort of briefing students to change their view of simulations as engineering tools. It seems that a much longer-term mindset change, developed throughout the course of the chemical engineering program, is required to enable them to start to see simulations as an opportunity for gaining understanding.

Complexity • The use of ChemSep did compromise the approach of the simulation to reality. Approaching reality would have required the use of a package such as AspenPlus, but as discussed below, this was not familiar to the students. In this case we had to choose familiarity over complexity.

Peer-interaction learning environment • The majority of the students thought that performing the simulations in pairs was helpful because it allowed them to share ideas and build on each others’ knowledge. An example of a pair using interaction to their benefit is given below:

Bongani: “*Ja, it was useful, because you can just get his view and then analyze it and compare it to what I think . . . if I go against it then we discuss it.*”

The students in this study felt that an interactive environment is essential for facilitating learning, confirming what was found in the literature.

Thorough instructions • Many of the students were critical of the structure of the simulations tasks and suggested that it may be improved with fewer, more focused questions, consisting of “baby steps” that would guide them to the final answer (a similar structure to their tutorials). Clearly the students did not like the open-endedness of the questions.

Many students began the exercises believing that they would be able to do everything and were unsure when confronted with a new, conceptual approach. Their immediate response was to guess answers. The large amount of guesswork showed that some of the benefit of the simulation was lost through lack of prior theoretical knowledge, despite the exercises being based on work already covered in class.

Familiarity with package • Using a familiar package improved the learning potential for working with the simulation, since students were able to focus on the conceptual issues being explored as opposed to worrying about navigational aspects. The decision to use ChemSep was vindicated since none of the students had any navigational difficulties. This also reduced the time required for the exercise.

Time for engagement • In this simulation exercise time was limited, but it seems that the view students held about simulations (as engineering tools rather than learning tools) was the major factor hindering engagement, rather than time pressure.

Learning history • The physical learning history was not beneficial. The majority of students abandoned it relatively quickly in favor of memory, which may not have worked for a more complex simulation. The benefits of an automatic learning history could not be studied due to the use of ChemSep. A physical learning history proved not to be a substitute for the stop/rewind/restart functionality.

Open-ended • The simulation tasks were designed to be open-ended. Evidence that the open-ended structure to questions was a distraction was noted in the first simulation task, where students were asked at which feed-vapor fraction it was best to operate the column in order to achieve a distillate benzene purity of 95%. All the pairs based their decision solely on

maximum purity, with no regard for the effects on column size or cost. This question was again posed in the interviews and students were presented with a table of variables that were important for the decision. This eliminated the problem’s open-ended status, but each pair showed conceptual deepening in their responses. Ideas of column size, energy requirements, and cost were mentioned. It appears that there is a fine line between allowing for an open-ended structure and helping students to explore all the variables necessary for developing a conceptual understanding.

Consolidation • Some students clearly indicated that the exercise had deepened their understanding, but felt that it had not been consolidated and so any benefit had been lost. They

felt that if the post-test had been written immediately or if they had been allowed to write down their numerical answers or summarize observed effects while performing the simulation, their new understanding may have been cemented. One issue raised by a student was that he would not consolidate any understanding unless he was certain that his answers were correct; the need for a model solution was identified. This is symptomatic of a far deeper problem involving students’ lack of self-confidence.

CONCLUSIONS

This study has identified a number of findings that have significant implications for designing simulation exercises that can

facilitate conceptual understanding.

Finding 1. There is a need to differentiate between students’ physical interaction with a simulation package and conceptual connections that are key to engagement.

It was clear in this study that all student pairs interacted with the simulation (surface approach), but only two pairs actually deepened their conceptual understanding and mentally engaged with the concepts (deep approach).

Finding 2. There seems to be a strong correlation between enjoyment and engagement.

In this simulation exercise, enjoyment facilitated engagement.

- Students who expressed having enjoyed the tasks showed an overall progression in their conceptual approach.
- Student enjoyment is therefore important for simulation exercise design.

TABLE 9
Overall Improvement and Students’ Expressed Enjoyment

Names	Improvement			Enjoyment		
	Regressions	Progressions	Overall	Yes	Partial	No
Bongani	0	5	5	x		
Gershwin	1	5	4	x		
Nandi	0	4	4	x		
Mpho	1	4	3	x		
Sizwe	1	4	3	x		
Thandiwe	1	4	3		x	
Arkash	0	3	3			x
Delia	1	0	-1		x	
Vani	1	0	-1		x	
Carey	2	1	-1			x
Jarrod	3	1	-2		x	
Olivia	3	1	-2			x
Richard	4	1	-3		x	
Derek	3	0	-3		x	

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