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Using Variation to Enhance Learning in Engineering*

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This paper reports on an attempt to enhance the learning outcomes obtained from a computer simulation aimed at extending students' understanding of distillation. The approach taken draws on a contemporary education perspective known as variation theory. The design uses the notion of a learning study to identify the key aspects of the learning situation. In-depth interviews were used to gain insights into the learning outcomes of the redesigned simulation experience. The overall finding is that the students were able to draw on their previous knowledge and expand it in ways that made them feel positive about the experience.

Keywords: variation theory; learning outcomes; computer simulation; distillation

INTRODUCTION

IN OUR chemical engineering programme we often draw on computer simulations to complement our teaching. A particular example is a computer simulation of the distillation process which is used in our third year as a laboratory task. Here we had become increasingly concerned about the nature of the learning experience that this simulation was able to evoke for our students—in its existing form the majority of students appeared to bypass the engagement that we had hoped they would enter into with the simulation. However, when we looked at the simulation we saw a potentially rich and rewarding learning experience, and so we decided to explore why the students' interaction so seldom appeared to move beyond simply going through the motions in order to complete what was required of them, and how we could possibly change that experience.

We are all associated with the Centre for Research in Engineering Education which is situated in the Faculty of Engineering and the Built Environment at the University of Cape Town, and with this background we started looking into what kind of developments were emerging in the student learning literature that we could draw on for our problem. Here we found an intriguing description of a learning theory that researchers, particularly in Sweden and Hong Kong, are busy developing and exploring in school classrooms (for example, see [1–3], and more recently [4]). This learning theory is about learning through variation. Further searching in the literature, however, revealed no reports of educators having explored the theory in university engineering situations, but the possibilities described in the example literature just listed inspired us to proceed, not only for the possible development of our teaching and learning, but also for colleagues in the engineering education community.

VARIATION THEORY OF LEARNING—A BROAD OVERVIEW

A full explorative description of variation theory is neither necessary nor appropriate for this article, and we refer interested readers to the references listed in the previous paragraph for more detail than we will now give.

Variation learning theory emerges from the phenomenography research tradition (for example, [5–7]) and as such it provides a theoretical framework for characterizing learning through an 'anatomy of awareness'. The fundamental attribute of the theory is that the kind of learning we want our students to achieve foremostly requires *discernment* of critical attributes of what is characteristically called the *object of learning*. In short, to discern something means to be able to differentiate amongst the various aspects of a phenomenon. Here, in teaching, what is called for is the creation of a focus on the most relevant aspects of the object of learning in order to explicitly raise them to the fore for the purposes of enabling learning. Thus the theory posits that without such a pattern of *experienced variation* there can be no discernment, and without discernment there can be no learning.

So, in essence, variation theory brings the following educational principle into explicit

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consideration: When a particular aspect of an object of learning is varied while other aspects are kept constant, the varying aspects are what will be discerned or come to the fore in a student's awareness.

When we discussed this idea amongst ourselves we recognised that many teachers, be they working at school or university level, use variation in some form in their teaching. In our own teaching we easily identified instances of using variation when, for example, giving many problems of the same type with variation in the numerical formulation. At the same time we found it extremely hard to recognise instances in our own teaching where we *explicitly* used variation as an educational tool. In other words, planning was not seen to be given to establishing a deliberate pattern of variation for our students to experience. This became our challenge for the distillation computer simulation—how could we draw on variation theory to redesign the distillation simulation as a step towards creating a better learning environment.

From what has been described above, it may be thought that *repetition* is undesirable. But repetition of itself is not necessarily undesirable, it is just the nature of the repetition, which depends on the purpose and focus of the repetition. If repetition is done without changing the focus of the problem, then it becomes simply rote learning. However, if the repetition focuses on different aspects of a phenomenon each time, then it is purposeful repetition, and can lead to understanding [8].

If, when learning to solve a particular type of problem, all that varies is the numbers, the learning potential becomes limited, and all one can learn is how to perform a certain procedure for solving those problems. If, on the other hand, what varies is the approach to solving such problems, then a whole new dimension of variation is opened up, and with it the opportunity to learn different approaches to solving these problems.

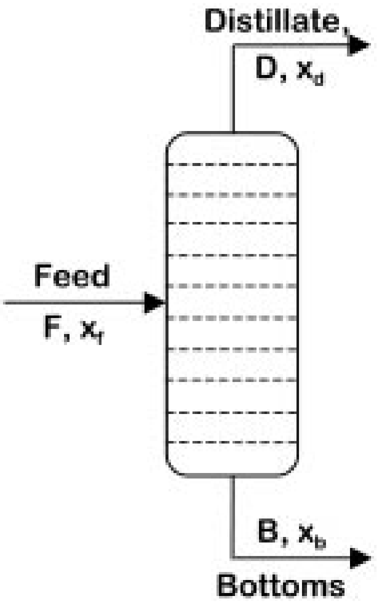

Fig. 1. Diagram of a continuous distillation column.

THE REDESIGN OF THE DISTILLATION SIMULATION

In our third year, distillation is presented as a process by which a mixture of compounds is separated on the basis of their boiling points (see Fig. 1). At this level distillation is characterised as a process that is normally carried out continuously by feeding a stream of the mixture into a column that consists of a number of trays. A 'distillate stream', containing mostly the components with the lower boiling points, is drawn off the top of the column and a 'bottoms stream', containing mostly the higher boiling components, is taken out of the bottom of the column.

To make use of variation theory as a fundamental guide to analyse and redesign the simulation we needed to identify the necessary key aspects of the learning situation. To do this we drew on the notion of a *learning study* as described by Pang and Marton [9]. This notion incorporates *design experimentation* (such as described in [10, 11]) and Japanese and Chinese *lesson study* characterizations (such as described by [12, 13]). In brief, these aspects are used to 'develop innovative learning environments and to carry out research into theoretically grounded innovations' while drawing 'upon teachers' valuable experiences into the research lessons to improve teaching and learning' [14].

The aspects of such a learning study to which we gave attention are now described together with how we addressed them:

1. *Choosing the object of learning*—a capability, appreciation or understanding to be developed. The original object of learning had required students to set up a distillation problem in the simulation program and use it to explore how a number of different parameters affected the functioning of the distillation column. This translated into the students being asked to change six different parameters affecting the operation of the simulated distillation column and observe their effects. Our redesign evaluation was that the dual objectives (setting up and exploring) detracted from the possible learning that could take place, and also that there were too many things being varied in a single exercise.
2. *Gaining insight into students' existing understandings, by, for example, an analysis of student learning research in the area, or some pre-lesson test.* A pre-simulation test showed that few students had good functional knowledge of distillation. A subsequent evaluation of the scheduling possibilities for our third-year laboratory exercises showed that most students would not have had any formal theory of

distillation classwork before the laboratory exercise, and hence there was no obvious past experience of distillation they could draw on for the simulation learning experience.

3. *Planning and implementing the learning experience.* Following (1) above we decided to reduce the breadth of possible learning by presenting the students with a problem already set up and running on the simulation program. Following (2) above we located this learning experience when the students had all recently covered the theory of distillation, and used noted conceptual difficulties to limit the simulation program parameters that could be varied from six individual entities to two. We first tried a pilot revised simulation where the students were asked to examine the performance of a set of three distillation columns, each with a different numbers of trays. These were typically treated as 'black boxes,' and answers to the questions posed could have been deduced from theory rather than from exploration opportunities afforded by the simulation exercise.

   This led us to develop a better set of exercises, which started with preliminary tasks designed to encourage the students to manipulate the simulation as a way to explore possible solutions prior to commencing with the main exercise. The focus of the exercise was also shifted to the internal operation of a *single* column, so as to give students a new window on what was happening in a column, as well as moving towards exploration of results that could not readily be predicted by theory (for the multicomponent system being examined). Appendix 1 lists the final set of tasks given to the students, in which the functioning of a distillation column with respect to a limited number of parameters was explored by varying those parameters.
4. *Evaluating and revising the learning experience by using a post-lesson study, such as interviews with students, or a test to look at to what extent the students have developed the desired learning outcome.* This evaluation phase should also look at how the object of learning was handled. The evaluation is discussed in full in the Results section. The approach to this evaluation was something we gave much consideration to. In the end we decided that for a study such as this a set of in-depth interviews would offer the greatest potential for teaching insight, both in terms of learning and in terms of how the object of learning was handled.

RESULTS

The evaluation of our redesigned simulation exercise was done with nine pairs of students who had recently been taught the theory of distillation. These pairs were selected from a set of volunteers to represent both the spectrum of ability and the range of backgrounds in the class. Each pair was observed during the exercise and then interviewed immediately afterwards (see Appendix 2 for the questions used). Each interview was audio recorded.

The interview recordings of the interviews were transcribed for analysis. The transcribed data together with the observation data were then analysed to determine the results of the exercise, as described below.

Here we should point out that the tasks were not prescriptive, and that the participating students were expected to make their own decisions as to how much to vary the parameters. It should also be noted that when students interact with a simulation they can constitute what they are learning as they go along.

The following describes how we examined the effectiveness of drawing on variation theory to broaden what it is possible to learn in a teaching situation such as the one we have described. Because we were looking for teaching insight, both in terms of learning and in terms of how the object of learning was handled, we have presented the results in terms of the following themes that emerged from the data:

Experiencing enhanced learning opportunities

What follows are some typical descriptions that students gave us about their learning experiences (all names are pseudonyms):

> Kerry: '(I) only knew feed tray location was important to get the pretty McCabe picture. It was nice to see the practical application of the feed tray location.'
>
> Tracy: 'This simulation is better than (the one we used in the Separation Processes course) because you can see the individual components and how they change through the column. HYSYS [the simulation package] had nice tables which showed the inside of the column.'
>
> Greg: 'Dead zones; if you increase the number of trays too much you get dead zones, I didn't know that . . . I didn't know there were dead zones.'

From statements like these we would argue that the students identified for themselves that they were looking at distillation columns with new discernment. The simulation exercise therefore provided an environment in which enhanced learning could take place.

What is significant here is that the opportunity for learning can be characterised as enhanced by narrowing the objectives of the exercise.

Drawing on previous knowledge of distillation in a meaningful way

During the simulation exercise students were required to increase the purity of the distillate by varying the number of trays in the column. Eight out of the nine pairs of students immediately knew that they must increase the number of trays in order to increase the purity, illustrating how the students drew on their previous knowledge of distillation columns.

The only pair of students that did not increase the number of trays in the column in order to increase the purity of the distillate, made the following comment:

> Interviewer: 'When we asked you to change the number of trays to increase the purity, you first decreased the number of trays. Why did you think that decreasing the number of trays would increase the purity?'
> Sarah: 'I wasn't thinking. I was just . . . (laughs).'

Such descriptions have been taken to indicate that as soon as the students had decreased the number of trays, they realised that they should not have done so and that they had not earlier discerned its significance.

That critical elements of what the students were discovering were being discerned in the light of their previous knowledge is illustrated in the following example.

> Jason: 'Our (distillation) knowledge isn't amazing, so it was nice to put things in and then it would trigger things like oh, if you put the feed stage here it gets a better composition or if you have a high reflux it will give you a better composition.'

The triggering indicates that these students were able to put what they observed into a meaningful framework.

It was also interesting for us to note that some students started to appreciate the importance of their prior knowledge for their learning about distillation. For example:

> Chris: 'You needed to know the theory before doing the simulation.'

The timing of this exercise relative to their course on distillation meant that previous knowledge would be available to them.

What was focused on?

The concepts mentioned most often in the interviews were *feed tray location* and *number of trays*, which were the parameters that were varied the most. These were clearly the concepts that the students focused on the most.

The recognition of learning

What was surprising was that the students in only two out of the nine groups felt they had learned something new about distillation columns. Probing of the other seven groups revealed that they clearly had learned something new. Evidence for this may be seen in the following student comments:

> Thandi: 'See, (the simulation) actually help you understand what you are doing in class much better.'
> Lebo: 'It's much easier to actually learn from doing something than just someone telling you that this is going to happen.'
> Jason: 'Like when changing your feed location, things are changing, rather than just in the lecture being told things change.'

From the discussion above, we would argue that both feed tray location and number of trays (both topics they were already familiar with) were seen in new ways by the students. This is also true of the concentration profiles in the column. Dead zones, which is a concept they had not encountered before, was also something new they had learned.

It appeared at first that these students had a very narrow concept of learning, which did not include expanding their knowledge about something they already knew. On further reflection, it would seem that possibly the term 'new' might have confused the students and also that the students are not used to articulating learning in these terms (they normally have their learning assessed in conventional tests that largely involve problem solving).

Associating 'playing around' with a system with learning

In many of the interviews students mentioned the idea of 'playing around' with the system. This poses the question of whether the students associate playing around with the system with learning.

> Interviewer: 'Do you guys feel you learned anything new through doing the simulation?'
> Carol: 'I think you could, if you played around with it a bit longer.'

Six of the nine pairs said that they would come back and fiddle with the simulation in their own time. Two more pairs said they would use it for a project, and only one pair said they would not play with it at all. Most of the pairs also indicated that they would be able to use this simulation for other purposes in the future.

The comment that students would come back in their own time and 'play around' with the system was unexpected. When asked what they would vary when they came back to the simulation:

> Roslyn: 'Reflux ratio, I'd like to (change) the reflux ratio.'

From this we infer that 'playing around' with the simulation means that they are wanting to explore the effect of another parameter on the system performance.

The students view of the revised simulation exercise

All the pairs said that they would have liked to have this exercise as a tutorial in their course on distillation. There were some suggestions that it would have been beneficial earlier in the course, as an introduction to distillation. If this were to be done, we imagine that the exercise would need to be redesigned to take account of any lack of previous knowledge. Another suggestion was that they would have liked to have set up the simulation for themselves (an interesting comment, given the way we had developed the exercise and done that for them).

The strong indications by the students that they would like to see this exercise as a tutorial in the Separation Processes course also shows how effective it was as a learning experience for them.

CONCLUSION

In this article we described how we drew on the variation theory of learning to redesign a distillation simulation exercise done by third-year chemical engineering students in order to open up discernment as a way to enhance the possibility of learning of distillation concepts. Results in terms of teaching insight, both in terms of learning and in terms of how the object of learning was handled, produced a number of insightful themes that pointed towards achieving better learning outcomes. For us, the most interesting *additional* insights were:

- that we needed to *narrow* the object of learning in order to *increase* the possibility for learning; and,
- the students did not easily recognise that exploration using a computer simulation was significant learning, even though they had clearly learned much through it.

At the same time we recognise the method we used for our evaluation could be improved in the following ways:

- by taking videos of the students handling the object of learning;
- by undertaking a much more in-depth study of the key conceptual difficulties in the object of learning from the students' perspective; this could also be accompanied by the development of a set of questions which would probe students' understanding of key concepts associated with the object of learning, to be used to test improvements in understanding.

The main purpose of this article is hence to share how we found variation theory to be a potentially powerful tool for helping us to improve student learning. In this regard, the particular aspects of variation theory we found most fruitful were:

- The nature of the variation used—is it just varying numbers in problems, or is it varying the approach to solving particular types of problems?
- The object of learning—has it been clearly defined, and is it too broad or too narrow?
- The sort of repetition being used—is it merely rote or is it purposeful (bearing in mind that a certain amount of repetition may be needed to develop a particular skill)?
- Are we allowing students to access previous knowledge and bring it to bear in this situation?
- Are we making use of the power of bringing different aspects of a phenomenon into students' focal awareness at the same time?
- Have we considered what students may be overlooking, as well as what they may be taking for granted, so that we can most effectively bring what we would like into their focal awareness.

Note that this study does not prove variation theory, but rather illustrates how it may be applied to the teaching and learning of a discipline such as engineering. A much more thorough study would be needed to demonstrate the effectives of learning as propounded by variation theory.

Another aspect that should be considered in future work would be to make the exercises more open-ended, as suggested by Strijbos *et al.* [15]. Our own experience in this regard, from a later study, showed that too much open-endedness could actually hinder student engagement with a simulation (Streicher *et al.* [16]).

Variation theory can be applied in a wide range of teaching and learning activities, but there are limited published examples in engineering education. Apart from our own work, we only know of a study by Carstensen and Bernhard [17], who used it to design a coherent set of exercises for electrical engineering students learning Laplace Transforms. It could also be used in structuring other teaching and learning activities such as lectures and laboratories. One of us has also applied variation theory in re-structuring the approach to teaching process control, using computer simulations together with lectures, problem exercises and laboratory work [18].

The use of variation theory in higher education appears to have an untapped potential that we can thus recommend to our engineering educator colleagues.

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APPENDIX 1: SIMULATION TASKS

The final simulation exercise involved the following set of tasks, all built around a distillation column simulation in HYSYS in which a multi-component mixture is separated into a distillate stream and a bottoms stream. Note that both pentane and hexane, used below, are intermediate components in the system being used (i.e. there are other components that are lighter than them and heavier than them):

1. Determination of various column operating parameters and profiles (these were the preliminary tasks) and then identification of the feed tray location from the column temperature and concentration profiles.
2. Variation of the feed tray location to find the optimum location for maximum pentane concentration in the distillate.
3. Variation of the number of trays (while keeping the same relative feed tray location) to find the minimum number of trays to achieve a particular pentane concentration in the distillate.
4. Determination of the positions in the column at which a particular pentane and a particular hexane concentration could be obtained, for a fixed number of trays and feed location.
5. Discussion of the effect of increasing either the number of trays or the reflux ratio on the capital and operating costs of the column (this was something that could not be done using the simulation).
6. Identification of dead zones in the column for a column with a very large number of trays, and discussion of this phenomenon.

APPENDIX 2: INTERVIEW QUESTIONS

The following set of questions was used as a basis for the semi-structured interviews conducted with each pair of students:

1. Did you learn anything new about distillation columns through this simulation exercise?
2. Did this simulation reinforce any ideas about distillation? If yes, what were they? If no, why not?
3. Which theories about distillation became apparent in this simulation?
4. Which aspects of the simulation did you like?
5. Which aspects of the simulation did you not like? What would you change about the simulation and why?
6. What so you think were the objectives of this simulation (from a distillation point of view)?
7. Would you have liked to have done this simulation as a tutorial in your Separation Processes course?
8. Would you come back in your own time to work on the distillation simulation yourself? What aspects about distillation would you investigate?

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