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ABSTRACT

Previous findings from the study within which this research is located had uncovered students' approaches to learning in the context of a second year chemical engineering course. Using an analysis of students' reflections on their experience, the study has shown the existence of three approaches to learning in this context: an 'information-based' approach in which the intention is to gather and memorize definitions and formulae; an 'algorithmic' approach, in which the focus is on being able to do numerical calculations; and a 'conceptual approach', in which the main emphasis is on understanding, similar to the original formulation of the 'deep' approach (Marton and Saljo, 1976). In the research presented in this paper, students' responses to five conceptual probes based on a recycle system were analyzed, as well as their responses to a question regarding the purposes of related worked examples that were presented in class. This research supported the previous findings regarding the validity of the approaches that had been identified, gave an illustration of how these approaches manifested 'in action', and provided further evidence of the approaches used by individual students. (Contains 16 references.) (Author/CCM)

# Approaches to learning in a second year chemical engineering course

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## ABSTRACT

Previous findings from the study within which this research is located had uncovered students' approaches to learning in the context of a second year chemical engineering course. Using an analysis of students' reflections on their experience, the study had shown the existence of three approaches to learning in this context: an 'information-based' approach in which the intention is to gather and memorise definitions and formulae, an 'algorithmic' approach, in which the focus is on being able to do numerical calculations, and a 'conceptual' approach, in which the main emphasis is on understanding, similar to the original formulation of the 'deep' approach (Marton & Säljö, 1976). In the research presented in this paper, we analysed students' responses to five conceptual probes based on a recycle system, as well as their responses to a question regarding the purposes of related worked examples that were presented in class. This research supported the previous findings regarding the validity of the approaches that had been identified, gave an illustration of how these approaches manifested 'in action', and provided further evidence of the approaches used by individual students.

## CONTEXT

Material and Energy Balances (CHE231F) is a second year Chemical Engineering course at the University of Cape Town that has been a cause of concern for some time. Not only has there been a long history of high failure rates, but the poor retention of fundamental concepts that has been demonstrated in subsequent courses, would suggest that even those students who pass this course, pass with a low level of understanding. In 1998, the lecturer responsible for the course was motivated to do something about this long-standing problem, and, inspired by a personal pedagogy that placed a high premium on student learning, she implemented new approaches to teaching, assessment and curriculum. These changes, although within the constraints of the broader structure of the undergraduate program, were considered fairly revolutionary within the Chemical Engineering Department, and can be summarized as follows:

- **Course emphasis shifted** from almost exclusive prior focus on problem solving skills, to include an emphasis on understanding of key concepts, and a clear focus on student learning and metacognitive development.

- **Curriculum content reduced** by 25%, following the maxim "Cover less, Uncover more".

- **Teaching methods adopted to promote active learning**: greater student involvement in lectures by means of individual and group tasks, use of interactive handouts, weekly journal tasks to promote reflection on learning.

- **Assessment for understanding**: use of non-numerical 'conceptual questions', semi-open-book format, unlimited time in one of the class tests.

A strong emphasis was placed on achieving consistency between intentions, teaching approaches and assessment methods.

## THEORETICAL FRAMEWORK

The theoretical framework on which this study is based draws on constructs from two main areas of educational research. Firstly, the investigations into student learning in higher education by Marton, Entwistle, Ramsden and others have identified and shown links between student perceptions, approaches to learning and learning outcomes (for example, Marton & Booth, 1997; Marton, Hounsell, & Entwistle, 1984). Secondly, we have used the notion of metacognitive development, as developed and used by Baird, Gunstone and others in secondary school contexts (for example, Baird & White, 1982; Gunstone, 1994), in order to describe and analyse changes in student perceptions and approaches.

The concept of 'approach to learning', with the distinction between 'deep' and 'surface' approaches (Marton & Säljö, 1976), has exerted an important influence on both practitioners' and researchers' views of student learning over the last two decades (Entwistle, 1997). Entwistle ascribes the power and endurance of the deep/surface model to its validity, in that it describes what is to most educators a 'recognisable reality' (p214). An important aspect of the original formulation of approaches to learning is their dependence on context. Approaches to learning are not stable characteristics of individual students, but rather responses to particular educational contexts (Ramsden, 1988). It would therefore seem likely that deep and surface approaches will have different manifestations in different academic specializations. Ramsden suggests that in some science tasks a deep approach will demand an initially narrow concentration on detail, which taken on its own would appear to be a surface approach. By contrast in the humanities a deep approach will usually involve establishing a personal meaning right from the start of a task.

As far as we can establish there are not many examples of research which has sought to uncover the manifestation of approaches to learning in particular undergraduate contexts, especially when compared to the great body of statistical work in which these constructs are assumed to be present as originally formulated (for example, Meyer, Dunne, & Sass, 1992). One important example of work in the former category is that of Shirley Booth, who investigated students learning to write computer programs (Booth, 1992). Booth identified four distinctly different approaches which fall into two pairs describing the surface-deep dichotomy. The surface approach was represented by what were termed 'opportunistic' approaches. Under this category, students either used an 'expedient' approach, in which a previous program is identified which will fit the bill, or a 'constructual' approach, where elements from their previously written programs are cobbled together for a solution. In both of these approaches students did not really interpret the problem as such, but focused on the end product. On the other hand, students in this context using deep approaches, termed by Booth 'interpretative' approaches, actually interacted with the problem. Students using the 'operational' approach focused on what the program was going to have to do, while those using the more advanced 'structural' approach focused initially on the problem rather than the program specifications. Apart from the specific approaches identified, this study also differs from previous work on approaches to learning in that in this context 'approach' refers more to the initial response to the problem than to the overall strategy used.

In this study we followed a similar route to Booth in that we were interested in uncovering students' approaches to learning in the context of the CHE231F course. As a starting point we have assumed the validity of the construct of 'approach to learning', but in our analysis allowed the context-specific forms of approach to emerge from an iterative analysis of the data, rather than imposing the deep/surface model on our work from the outset.

In this study we will draw on Baird's useful description of metacognition as "the knowledge, awareness and control of one's own learning" (Baird, 1990, p184). Gunstone (1994, p. 133) describes learners as appropriately metacognitive "if they consciously undertake an informed and self-directed approach to recognizing, evaluating and deciding whether to reconstruct their existing ideas and beliefs". Gunstone argues that all learners are metacognitive in some way, and that teachers should be aiming to **enhance** their learners' metacognitive abilities. This involves helping learners develop appropriate metacognitive knowledge, and increase awareness and control of their own learning.

## THE STUDY

### Purposes of the study

The larger study in which the research presented in this paper is located, was in broad terms concerned with the student experience of the restructured CHE231F course. Specifically, we aimed to better understand the interactions between student perceptions of a course, student perceptions of their own learning (and their role in this), and teacher intentions and practices. The following research questions were formulated:

1. How do students perceive (make sense of / experience) the learning context in CHE231F, and how does this influence the way they approach their learning in this course, specifically in terms of how they learn, what they learn, and what they value?

2. In what ways do their perceptions, approaches to learning, and metacognitive abilities change as they progress through the course? What aspects of the course are associated with facilitating this change? What is the influence of assessment on this development?

The research to be reported in this paper falls under that part of the study concerned specifically with students' approaches to learning.

### Methodology

A wide variety of qualitative data was collected in the course of this study, including fieldnotes from class observations (the researcher attended almost all lectures and tutorials), test and examination scripts, student journal entries, and class marks. The central data come from a series of five (and in some instances, six) interviews conducted with 11 students over the duration of the course. These interviews were audiotaped and transcribed verbatim, and pseudonyms were assigned to individual students. Student data from journals and interviews can be classified into 'self-reflective data', in which students reflected on their experience of the course, and 'conceptual data', in which students revealed their understanding of concepts, often in response to conceptual probes that had been developed for use in the interviews (White & Gunstone, 1992).

The analysis of the data followed the established qualitative methodology (Denzin & Lincoln, 1994), and data was managed using the NUD*IST software package.

## Previous findings relevant to the research

An iterative analysis of the self-reflective interviewee data showed the existence of three different approaches in the context of CHE231F. These are

1. a **conceptual** approach, where the intention is to understand concepts
2. an **algorithmic** approach, where the intention is to remember calculation methods for solving problems
3. an **information-based** approach, where the intention is to remember information that can be supplied in response to assessment questions

The designations 'algorithmic' and 'conceptual' were given to these approaches following the distinction drawn by Niaz (1995). Although Niaz used these terms to describe different kinds of assessment items, we think that our use matches the intentions in his work (i.e. to distinguish between different modes of engagement with the items). The term 'information-based' was formulated following one particular interviewee's repeated use of the term 'information', and her description of how and why she focused on acquiring information when she was struggling with a topic in the course[1]

The three categories of approaches identified are illustrated in the following representative quotes:

Conceptual:

> *I just hate it when I do something and I can't understand exactly what it is I'm doing. I'd rather leave something and not do it than do it and not understand what I was doing. (Thabo, interview 5, lines 339-341)*

Algorithmic:

> *And the thing is, I probably didn't understand, not totally, but often I didn't quite have an understanding of the process, I just knew how to do the calculations... (Geoff, interview 2, lines 699-701)*

Information-based:

> *I have to go over my notes again, I go over them sometimes, not like after each lecture and stuff, so it's like very important because I seem to forget like the small definitions and stuff. And the way they all apply, and ... I sometimes just forget the whole thing (Shakira, interview 4, lines 85 – 89)*

In both of the latter approaches the primary intention is something other than to understand. If we now compare these approaches with the original deep and surface approaches (Marton & Säljö, 1976), it would seem that the conceptual approach is almost identical to a deep approach. The information-based approach is most similar to the original formulation of the

[1] The interviewee was Nomsa. She used the term 'information' on a number of occasions in the first four interviewes (e.g. Interview 1 lines 118-119. Interview 3, lines 453 – 453). In the fifth interview the interviewer asked her what she meant by the use of this word (lines 179 - 200).

surface approach; nonetheless we would suggest that both the algorithmic and information-based approaches could be seen as forms of the surface approach particular to this context.

It is critical to bear in mind our focus on intention and not on actions, as some actions can be used to different ends. Doing problems can be used either to develop understanding, or to remember calculation methods, and using the textbook and lectures can be used either with a conceptual understanding intention or with the intention of gathering information.

Following from the development of these constructs, the same data were examined in order to classify the approaches adopted by individual students. Given the 'naturalistic' style of the interviews(Lincoln & Guba, 1985), it was not always easy to deduce approach from student comments, and so in interpretation we tended to err on the cautious side. A word that presented particular difficulty was that of 'understand' – almost all students spoke about 'understanding their work', 'not understanding' – but we would suggest that this does not automatically imply a conceptual approach (Case, Gunstone, & Lewis, 2000). We have looked for a broader and deeper discussion than the mere existence of particular words in order to infer approach.

The approaches adopted by individual students are summarized in Table 1, and discussed and elaborated in the following paragraphs.

**Table 1: Summary of individual approaches to learning**

| INFORMATION-BASED | ALGORITHMIC | CONCEPTUAL |
|---|---|---|
| | John | **John** |
| | Thabo | **Thabo** |
| | Mike | **Mike** |
| Eddy | | **Eddy** |
| Lindiwe | | **Lindiwe** |
| | **Andrew** ⟶ | |
| | **Geoff** ⟶ | |
| | **Thembi** ⟶ | Thembi |
| **Nomsa** | Nomsa | |
| **Shakira** | | |
| **Maria** | | |

Key:
**Bold**: primary approach
Non-bold: secondary approach used in conjunction
⟶ : direction of metacognitive development

Students who exhibited a clear use of a conceptual approach from the start of the course were John, Thabo, Eddy, Mike and Lindiwe. Each of these was able to articulate clearly that they used such an approach, in whatever they did focusing primarily on conceptual understanding. There were interesting differences in the methods they used to achieve such understanding. Eddy and Lindiwe spoke more about using the textbook to achieve this, while the other three generally found the textbook unhelpful and tended to develop understanding through doing problems. Although these students were strongly committed to a conceptual approach, this being something that had developed prior to starting CHE231F, they also used algorithmic and information-based approaches where this could achieve the desired end in assessment.

Nonetheless they remained strongly critical of these 'non-understanding approaches' and felt that in order to succeed in a course such as CHE231F a conceptual approach was essential.

The other six interviewees were not firmly set in the use of a conceptual approach from the start of the course, and differed both in terms of the approaches used, and in the nature of the metacognitive development they showed during the course.

Over the course of the interviews both Andrew and Geoff became critically aware of their use of an algorithmic approach, and spoke at length of what they were doing especially when this had led them into difficulties in the conceptual probes. They became increasingly critical of this approach, and aware of the importance of using a more conceptual approach. Andrew was also particularly critical of an information-based approach, although this often seemed related to his dislike of the effort that such an approach would require.

Thembi seemed to display a slightly different manifestation of the algorithmic approach, in that she was focused on trying to find the perfect solution method that would suit all problems. She also seemed to have a more developed awareness and ability to use a conceptual approach, and was quite articulate in her criticisms of both an algorithmic and an information-based approach. Her actual use of this approach seemed hampered more than anything else by her struggles with time.

Nomsa's primary approach to learning in CHE231F was information-based, and she was able to describe at some length her motivation for this approach, which she had used with considerable success at school and in first year. However, in comparison to the other students using an information-based approach, she actually worked through problems on her own, and was concerned with improving her problem-solving skills, which we would take to indicate an algorithmic approach.

Both Shakira and Maria exhibited an exclusive preference for an information-based approach, to the extent that each of them only actually started doing problems on their own right at the end of the course. An interesting background fact is that these two students are the only two in the sample who had changed to chemical engineering from doing science degrees. They both commented that the information-based approach had worked for them in this context, and it caused them considerable frustration that this previously successful approach was no longer working.

If we consider the metacognitive development of these six students who did not use a conceptual approach from the start of the course, there is a distinct difference between those using an algorithmic approach, and those using primarily an information-based approach. Thembi, Geoff and Andrew all displayed explicit increased awareness of the importance of a conceptual approach (and the limitations of the algorithmic approach), although they were not totally successful in being able to convert this awareness into control of how they approached their learning in CHE231F. Nomsa and Shakira made almost no statements in this regard, while Maria made some comments which could be interpreted as an increased awareness of the need to consider the physical situation behind the numerical problems, but no coherent scheme of how to achieve this in practice.

## Aims

In the research which is the focus of this paper, conceptual data was analysed for evidence of students' **use** of specific approaches, in order to provide a measure of triangulation with the approaches that had been derived from the self-reflective data. Conceptual probes were used in the first four interviews which took place before the final course assessment. An analysis of data from the second interview will be presented in this paper.

## Procedure

During the second interview, students' conceptual understanding in a particular content area (recycle systems) was investigated, using probes which were based on a series of examples that had been worked through in lectures. During the presentation of these examples we had started to suspect a divergence between the lecturers' intentions and the students' perceptions of the purposes of these tasks. The lecturer was hoping to develop students' conceptual understanding of recycle by presenting systems that differed slightly from each other in critical respects, while it seemed to us that students were focused on the mechanics of the calculations and the use of the input-output table. It was decided to follow up this idea in the second interview, using these examples as a basis for discussion. The questions we formulated were deliberately 'non-numerical' and conceptual in nature.

The worked examples were all based on a system using the reaction in which ethylene reacts with oxygen to form ethylene oxide:
ethylene (E) + ½ oxygen (O) → ethylene oxide (EO)
The symbols for the various chemical species are those commonly used by chemical engineers, even though they do not conform with standard IUPAC terminology.

The first four probes are based on the system shown below in figure 1:

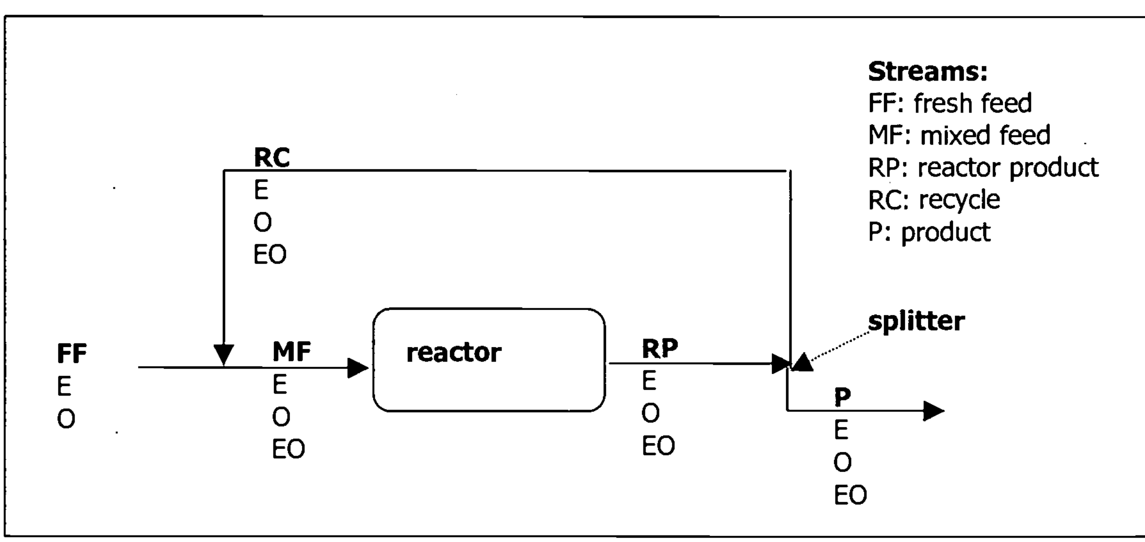


**Figure 1 Recycle system with no separation, product stream acts as purge**

In this system the chemical reaction given earlier takes place in the reactor. However, not all the reactants are converted to products, hence the mixed composition of the reactor product (RP) stream. In order to improve the overall yield of product, some of the RP stream is split off by the splitter and diverted back into the reactor via the recycle (RC) stream. The process given here is defined as having reached steady state, i.e. there is no change in the concentrations of the various streams with time.

The term 'conversion' refers in general to the percentage of reactants (E and O) that are converted to products (EO). Overall conversion is the nett conversion over the whole process (i.e. compare the amounts of E and O in the fresh feed with the product stream) and conversion per pass is the conversion over one pass through the reactor (i.e. compare the mixed feed with the reactor product stream). These are all concepts that students had been introduced to in lectures over a period of some weeks.

The following four probes were based on this system:

1. Use the diagram to explain what is meant by overall and per pass conversion.

2. In the system given here the overall conversion is given as 75% and conversion per pass as 50%. Are these two quantities always different, and if so, is overall conversion always greater than per pass conversion?

3. What could be done to this system in order to increase per pass conversion?

4. What could be done to this system in order to increase overall conversion?

The fifth probe was based on a slightly different system, in which the splitter is replaced by a separator in order to give a pure ethylene oxide product stream, and a recycle stream composed only of unused reactants. This system is shown below in figure 2:

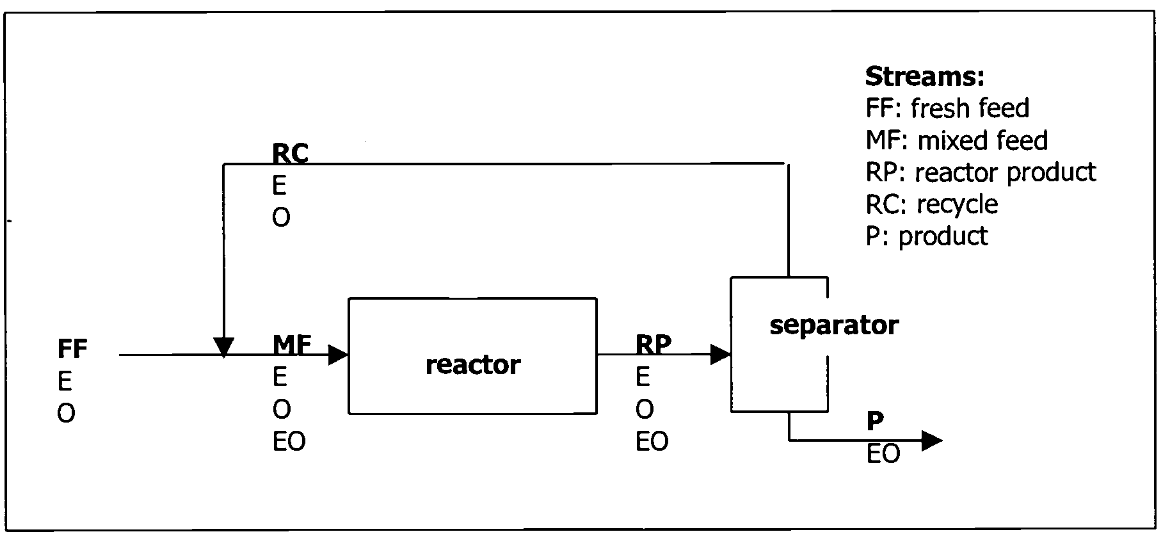


**Figure 2 Recycle system with ideal separation**

The fifth probe was as follows:

5. What is the overall conversion in this system? Explain your answer.

Students were also asked before and after the probes what they thought the lecturer's purpose had been in presenting this particular set of worked examples in class.

Interview transcripts were analysed for evidence of the approaches identified earlier in the analysis of self-reflective data. This was done first of all in an analysis of the responses to each probe, and then in an analysis of the responses of individual students.

## RESULTS

### Conceptual probes

Student responses to the five probes will be discussed in turn, after which the results will be summarized and compared with the other findings discussed earlier.

Probe 1: Overall and per pass conversion

This probe provided a starting point for the discussion, and an opportunity to clarify the meanings for these terms held by the interviewee, which we considered important to establish before presenting the subsequent probes. At first glance one would think that this probe would merely require an information-based approach for an adequate answer, in that it could be described as a recall of definitions. However, an analysis of the responses revealed the existence of both algorithmic and conceptual approaches to dealing with this question, and suggests that a conceptual approach was needed in order to be able to use these definitions appropriately in the context of a given system.

Responses to this probe comprised two parts: firstly a definition of conversion, and secondly a differentiation between overall and per pass conversion.

In the first part we identified both algorithmic and conceptual approaches. In an algorithmic approach, the formula for calculating conversion was recited:

> *...moles of this in minus moles of that out, divided by that out. (Eddy, lines 343-343)*[2]

Responses in which students were able to explain without using a formula what was meant by conversion were classified as conceptual, for example:

> *...how much of the reactants are converted into products. (Nomsa, lines 344-345)*

In the second part of these responses, differentiating between overall and per pass conversion, we found that students needed to identify a particular location in the system, ie. considering the whole system for overall conversion, and the reactor for conversion per pass. The two students who could not provide satisfactory answers to this probe (Andrew and Shakira) both were not able to identify the correct locations for overall and per pass conversion. For example, Andrew suggested that conversion per pass would refer to the reactor product stream as it goes through the splitter, indicating that he hadn't grasped that conversion had to do with a chemical reaction that takes place in the reactor.

Geoff's response is also interesting in this regard in that although it could be considered a satisfactory response, his terminology of "conversion...**across** the reactor" (lines 352-353) is very likely conceptually weaker than students who referred to conversion taking place **in** the reactor. The possibility that this indicates an underlying conceptual gap is further strengthened by Geoff's comment in probe 3 that .

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[2] All quotes presented from here on in the paper are from interview 2.

*"You see I'm not sure – you see maybe my definition of a reactor is incorrect. I'm looking at a reactor as something that does something to your mixed feed [stream], so that you can get something out..." (Geoff, lines 288-290)*

This can be contrasted to Thembi's solidly conceptual response in which she stresses the purpose of the reactor:

*...per pass is mostly concerned with the reactor, so what it converts, that's per pass. (Thembi, lines 389-390)*

An algorithmic focus was further illustrated in Andrew's response when he suggested that how you calculate conversion depends on where you take a basis (lines 288-292). Here he has confused a concept that is always defined in the same way (conversion), with a calculation method that depends on the given information in a particular problem (taking a basis). Further on in his response Andrew makes repeated reference to the way the method that had been used to solve the problem in class (lines 384-386).

In her response Shakira seems to be clutching at statements remembered from lectures, which she is unable to explain in a conceptually or algorithmically sensible way. This we would identify as indicating an information-based approach:

*"Conversion per pass is... uh I think... overall conversion was I know in the reactor we say 75% is converted over there, and then it comes out... So that would be the overall conversion..." (Shakira, lines 268-269)*

Later on, when prompted to think of the purpose of recycle (in order to improve overall conversion), Shakira reveals another underlying conceptual problem when she says that

*... it's just so that the reactants, or the products, don't accumulate in the whole system. (Shakira, lines 307-308)*

Conceptual problems such as these and others identified earlier we would suggest are evidence of the absence of a conceptual approach.

<u>Probe 2: Overall greater than per pass conversion</u>

Due to the changing nature of the interview schedule, this probe was only used with 7 of the 11 interviewees.

All 7 students answered that these two quantities would usually be different, with two students (John and Thembi) able to reason that in the absence of a recycle stream they would be the same. Students who were able to correctly reason out that overall would always be greater than per pass conversion in all cases used a conceptual approach, for example Thabo:

*... with a recycle stream you continually have unreacted feed coming back into the product. Therefore increasing the amount of product you're getting. So that is why... (Thabo, lines 471-473)*

There are two pieces of evidence of students attempting an information-based approach in this probe, i.e. recalling relevant information from lectures or classes. Eddy said that *"you can have 100% overall conversion, and then maybe say a 50% per pass conversion or something like that"* (lines 363-364), but he was not able to proceed much further in answering the question. Shakira also referred to the situation in the given system but was not able to expand to the general case.

There was no evidence of an algorithmic approach in response to this probe, a finding which doesn't surprise us, as this probe does not easily lend itself to a purely calculation-based approach. Such an approach would require a fairly complex algebraic derivation, which would in any event most probably depend on a reasonable conceptual understanding.

Probe 3: How to increase per pass conversion

This probe required students to use their conceptual understanding of the nature of the actual process in order to realise that per pass conversion had to do with the chemical reaction happening in the reactor, and therefore in order to change it the conditions in the reactor (temperature, pressure, etc.) needed to be changed. Up to this stage the mass balance calculations in class had involved only the streams surrounding the reactor, and so this probe required students to think beyond the possibilities presented in class. Quite a few of the interviewees suggested changing the composition of the mixed feed stream. Although this answer is also technically correct, we would argue that it is conceptually weaker, in that it is not referring to the primary issue (the reaction conditions). Students who gave this response were generally not able to explain why they would make such a change, and we would therefore suggest that this response is related to the usual themes of the mass balance calculations in class, which tend to be generally concerned with stream compositions. Lindiwe was one student who gave the initial answer of changing the composition of the mixed feed. She was then prompted to think of other ways of changing the per pass conversion, and her response provided an interesting illustration of possible stages in a shift to a more conceptual approach:

> *Interviewer: OK. Any other things you think you could do to increase the conversion per pass?*
> *Lindiwe: In the reactor?*
> *Interviewer: Yes ja, conversion per pass.*
> *Lindiwe: Does conversion like... um depend on how easily the reaction takes place?*
> *Interviewer: Yeah, what do you think? How can you make it happen more easily?*
> *Lindiwe: More easily. Um, catalysts, I guess.*
> *(Lindiwe, lines 243-251)*

Different aspects of an algorithmic approach are illustrated in students' responses to this probe.

In some responses students attempted to use the formula for calculating per pass conversion, but this does not lead to a conceptually satisfactory answer:

> *Per pass conversion .... It's the moles of that [MF] minus that [RP] divided by what's coming, right? So if you make what comes in here smaller, then that would increase your per pass conversion. (Eddy, lines 395-398)*

Instead of realising the conversion per pass depends on the chemical reaction that happens in the reactor, Eddy has grasped at the formula that was given in class for calculating per pass conversion, and is assuming that this formula can be used to reason out how to increase pass conversion. This formula is given as follows (using the abbreviations from figure 1):

$$\text{Percentage conversion per pass} = \left(\frac{\text{reactant in MF} - \text{reactant in RP}}{\text{reactant in MF}}\right) \times 100$$

It may seem difficult to figure what Eddy is doing incorrectly here, as this sort of reasoning is often used in scientific calculations. The problem is that he has assumed that all the variables are independent (as they are for example in the formula F=ma). In this instance however, changing the denominator will cause changes in both terms in the numerator, and it therefore cannot be used to determine changes to the conversion per pass. The problem here we would argue is that Eddy is using an algorithmic approach without the underlying conceptual understanding.

An analysis of Andrew's response to this probe illustrates a different aspect of an algorithmic approach:

> *Andrew: "You'd make this stream [RP] bigger."*
> *...*
> *Interviewer: "How would you increase that stream?"*
> *Andrew: "I don't know.... The question was stated 50% [conversion per pass], so if they said it's 60 you'd just have* ***changed the numbers*** *accordingly."*
> *(Andrew, lines 499, 508-510, 515-516, authors' emphasis)*

From the above it can be seen that Andrew has failed to even engage with the question as he doesn't see the point of the question. For him it doesn't matter how one would increase conversion per pass, what matters is how to do the calculations when given a certain value for conversion per pass.

Evidence of this same attitude can be seen in the initial responses from Thabo and Mike, both of whom expressed surprise that I could ask such a question, and indicated that it was not something they were inclined to think about:

> *No actually I've no clue as to why the conversion is 50% per pass, but it seems to work out for me, so.... (Thabo, lines 408-409)*

Probe 4: How to increase overall conversion

The worked example given in class around this system had involved two sets of calculations, one in the case of a 75% overall conversion and the other for a 90% overall conversion. The lecturer's intention in doing these two calculations was to illustrate that in order to increase the overall conversion the recycle ratio has to be increased (more of the reactor product split off to the recycle stream).

In students' responses to this probe we identified three modes of engagement: either to recall the conclusion from class (information-based), to use the calculations given in class to draw the conclusion (algorithmic), or else to use a fundamental understanding of the purpose of a recycle system (conceptual). Once again students often exhibited more than one approach in the course of their response, for example quite a few students who initially recalled the conclusion from class (information-based), were then able to explain this using a conceptual or algorithmic approach, as illustrated in Thembi's response:

*Interviewer: What basically did you have to do to get this bigger overall conversion...?*
*You're welcome to look at your notes... or you can look at the numbers here......*
*Thembi: You recycled... wait wait... recycled more or recycled less... (laughter).*
*Interviewer: OK think about it...*
*Thembi: I think you'd have to recycle more...*
*Interviewer: To get a higher...?*
*Thembi: A higher overall conversion.*
*Interviewer: Why do you say that?*
*Thembi: Because then you would be putting in more reactants, and whatever went in, more of it is getting converted, cos you're recycling more of it. (Thembi, lines 357-370)*

Andrew's response to this probe again illustrates an extreme form of an algorithmic approach whereby he fails to engage with a question that is not focused on doing the calculation (similar to his response to probe 3). He is able to explain how to do the calculations if a 90% overall conversion is given, and refers often to the way he did that particular calculation, but is unable to explain what difference was made to the system in order to achieve that conversion:

*Interviewer: If you want a bigger overall conversion what were you doing?*
*Andrew: Just change the amounts here...*
*Interviewer: Change the amounts in the product stream?*
*Andrew: Ja.*
*Interviewer: How did you do that?*
*Andrew: It's 90%. Cos the basis was here (in FF), overall conversion 90%, ... and it's a ratio of 2 to 2, 1 to 1...*
*Interviewer: You're telling me how you solve the problem if you've got a bigger conversion... What I'm saying is what did that actually do to the system?*
*(Andrew, lines 615-623)*

Nomsa initially was unable to attempt an answer, but when prompted to have a look at the recycle ratio, her response indicates an algorithmic approach but coupled with a serious conceptual misunderstanding:

*Interviewer: Now tell me, for bigger overall conversion, what do you think you must do to the recycle ratio?*
*Nomsa: You must increase it. No you must decrease it, cos you want to have more coming over here (P), so therefore the RC ratio has to be smaller, because more of the... (Nomsa, lines 435-439)*

She is taking a larger overall conversion to imply a larger total product (P) stream, whereas it means only an increase in one component of the product stream (EO) and the decrease in the volume of reactants in this stream (E and EO) could in fact imply a lower overall flow rate.

Probe 5: Recognising 100% conversion

This probe is similar to the previous one in that three clear modes of engagements were identified: recalling information from class (information-based), doing stoichiometric calculations to prove that the reactant and product formed a 1:1 ratio (algorithmic), or else reasoning out 100% conversion on the basis of there being no left-over reactants in the product stream (conceptual).

When students had arrived at the answer using an algorithmic approach, the interviewer prompted them to consider other ways of arriving at the answer by looking at the composition of the streams. Andrew's comment following this interchange was indicative of his apparent negative attitude to thinking things out for himself:

*Interviewer: What else do you notice about this... Look at the product stream... Compare it to say this product stream in the previous system... What's different?*
*Andrew: Ja there's still reactants left.*
*Interviewer: So there's another way of knowing...*
*Andrew: Of checking.*
*Interviewer: Overall conversion.*
*(Andrew laughs)*
*Interviewer: If you've got no reactants here what can you always say...*
*Andrew: 100% [overall] conversion.*
*Interviewer: So think about that. What? You weren't sure of that...*
*Andrew:* ***Somebody should have told me that.***
*(Andrew, lines 425-438, emphasis added)*

Classification of individual students' approaches

Table 2 presents a summary of the approaches exhibited by individual students in their responses to the five probes. For this classification we have considered only students' spontaneous responses and left aside responses following prompting from the interviewer, even though these data were sometimes used in describing approaches above. It can be seen that on a number of occasions students used a combination of approaches in their responses. In classifying responses we decided to err on the cautious side, and therefore where there was not sufficient evidence to clearly identify an approach (usually only a one line response) we have marked the response as 'not classifiable' ('?'). We have also indicated where students did not attempt to engage with the probe without prompting from the interviewer ('no attempt'). Responses in the latter category, we suggest, are often indicative of not having a useful approach (algorithmic or conceptual) to bring to bear on the problem. We have included in this summary an indication of whether the students' response was judged conceptually 'correct' or not. This basis for this classification was made with input from the lecturer (the third author) and another chemical engineering lecturer.

It is difficult to draw any firm conclusions from this table, except to notice some general preferences. There is a clear association between using a conceptual approach and obtaining a correct answer, which is hardly surprising, given the purposes of the probes.

There are some students who seem to make good use of a combination of different approaches; most diverse in this respect is Eddy, but John, Thabo and Mike all fall into this category. In general this pattern matches the earlier findings on these students: that although they had a preference for a conceptual approach, they made good use of other approaches where this seemed expedient.

**Table 2: Summary of interviewee's approaches to learning used in response to probes**

| Probes: | 1 | 2 | 3 | 4 | 5 | % correct answers |
|---|---|---|---|---|---|---|
| Eddy | A & C ✓ | I | A | I & A ✓ | C ✓ | 60 |
| Nomsa | C ✓ | | ? | No attempt | A ✓ | 50 |
| John | A & C ✓ | C ✓ | ? ✓ | ? ✓ | A & C ✓ | 100 |
| Geoff | A & C ✓ | ? | No attempt | C ✓ | | 50 |
| Mike | A & C ✓ | C ✓ | A & C | No attempt | C ✓ | 60 |
| Andrew | A | | A | A & C | A ✓ | 25 |
| Thabo | C ✓ | C ✓ | A | I & C ✓ | | 75 |
| Thembi | C ✓ | C ✓ | C ✓ | I & C ✓ | No attempt | 80 |
| Maria | C ✓ | | ? | I | I | 25 |
| Shakira | I | I | ? | No attempt | C ✓ | 20 |
| Lindiwe | C ✓ | | ? | I ✓ | No attempt | 50 |

**Key:**
I: Information-based approach
A: Algorithmic approach
C: Conceptual approach
?: Not classifiable
✓ Correct response
No data for this probe

Andrew's strong preference for an algorithmic approach is quite notable, also that this approach without the backing of good conceptual understanding seems to be generally unsuccessful. The data for Geoff is more limited, and difficult to say anything further than that he shows evidence of using both algorithmic and conceptual approaches.

Thembi's use of a conceptual approach in four out of the five probes is notable, and seems to present a different picture than that deduced earlier from the self-reflective data. From other data we would suggest that in this environment, where there was no pressure from a time restriction, Thembi was able to make use of a conceptual approach, which in other contexts was hampered by her struggles with time (and she felt forced her into an algorithmic approach).

On the other end of the spectrum, the earlier finding that Shakira and Maria show a preference for an information-based approach is supported by this analysis. Their lack of use of an algorithmic approach is quite notable when compared to other students, and links to the finding that these were students who avoided doing calculations.

The data from these probes for Nomsa and Lindiwe is more limited than that for the other students. This we think is at least part due to their quieter personalities and less confident engagement with the interview situation. Lindiwe was particularly withdrawn in the first four interviews. The limitations of this particular data collection method were somewhat moderated in the broader study by the availability of other data such as journal entries. Drawing conclusions with regard to these two students is therefore even more problematic than the already tenuous findings on the other interviewees, yet it is interesting to note that in the two probes where their responses were classified there is some reflection of the earlier findings (Lindiwe: conceptual/information-based; Nomsa: algorithmic/information-based with gradual awareness of conceptual approach).

## Purpose of the examples

Students were asked both before and after the series of interview probes what they thought had been the purpose behind the presentation of these worked examples in class. These responses were analysed and can be grouped into the following three categories:

1. No particular purpose
   These are just introductory problems that would usually be presented at this stage in the course. In these responses no particular purpose could be identified for the presentation of these problems, for example:

   *Interviewer: These problems... Do you have a sense of... Are these just four...randomly picked recycle problems? Or is there any sort of specific reason she picked these four...?*
   *Andrew: I don't have a clue.*
   *(Andrew, lines 247-251)*

2. To learn how to do the calculations
   The lecturer used these problems to show how to do the calculations involved with solving recycle problems, with particular emphasis on choosing a basis and using input-output tables. Some responses in this category indicated that once you knew how to do these problems you'd then be able to tackle similar problems, for example:

   *Shakira: And then, ja, after that, I think it's just to give us a whole idea of what really happened in a recycle. And uh ja what's expected... I mean, these are problems that could result in....*
   *Interviewer: OK so it's to see, you said to see what happens in a recycle...*
   *Shakira: Ja.*
   *Interviewer: Tell me more about that?*
   *Shakira: It's like, um, where you choose your basis would be like very important (OK) like taking in the MF or in the FF. And then ja the recycle affects whatever's happening, and where you take your basis.*
   *Interviewer: So it's about practicing the calculations then and where to choose the basis and so on?*
   *Shakira: Ja.*
   *(Shakira, lines 240-254)*

3. To understand the concepts in recycle systems
   Responses in this category referred to the comparisons that could be drawn between these various systems once you had completed the calculations, and that this would enhance your understanding of the concepts.

*Eddy: So I'd say that probably that if you compare all of them all together, you probably end up that you know your compositions of your streams would be same, ignoring inerts, and even if you add inerts, or something like that.*
*Interviewer: What do you think is the point of doing those kind of comparisons?*
*Eddy: So that you don't get confused in the real world! (laughter)*
*(Eddy, lines 638-644)*

Given the purpose and format of the probes it was expected that a comparison of the before- and after- responses would show a shift towards the third category of response. The results are given in Table 3:

**Table 3: Comparison of students' perceptions of the purpose of the examples before and after engaging with the probes**

| | Before probes | After probes |
|---|---|---|
| Eddy | 1 | 3 |
| Nomsa | 2 | 2 |
| John | 3 | 3 |
| Geoff | 1 | 3 |
| Mike | 2 | 3 |
| Andrew | 1 | 3 |
| Thabo | 2 | 3 |
| Thembi | 2 | 2 |
| Maria | 2 | 2 |
| Shakira | 2 | 2 |
| Lindiwe | 1 | 1 |

**Key:**
1 no particular purpose
2 to learn how to do calculations
3 to understand the concepts

It is interesting to note that while only John stated the 'conceptual' purpose before the probes, the students who shifted to this purpose after the probes were largely those who have been shown earlier to use a conceptual approach (Eddy, Mike, Thabo) and others who had shown increased awareness of the need for a conceptual approach (Geoff and Andrew). The students who had been shown earlier to favour an information-based approach and had more limited metacognitive development, were less amenable to this change (Nomsa, Maria and Shakira). Thembi presents an exception to this finding, which we find intriguing given her strong conceptual approach to the probes. On one level at least this adds to a growing conclusion that Thembi's experience is markedly different to other students, and more complex to analyse especially given the unusual extent of her struggles with time pressure. On both occasions Lindiwe didn't engage with the question at all ("I don't know"), which we would ascribe more than anything else to her general engagement with the interview situation as discussed earlier.

## DISCUSSION

At the start of this paper we reported on earlier work where we identified students' approaches to learning from an analysis of self-reflective data. In this paper we have attempted to identify students' approaches to learning **in action**, in response to conceptual probes used in an interview situation. Firstly and most importantly, this analysis has provided evidence and further elaboration of the three different approaches. The algorithmic approach, in particular, has been shown to be an effective tool when reasoning through a probe, but only in conjunction with an underlying conceptual understanding (for example probe 5). We have also shown (probe 1) that using a definition in the context of a physical situation can require more than a mere recall of information.

The identification of approaches used by individual students provided a limited degree of confirmation of the earlier findings. We would not like to attach too much significance to this aspect of the present paper, but have included it for the sake of completeness. The comparison of the change in students' perceptions of the purposes of the probes did however provide some significant support to the earlier findings regarding students' metacognitive development.

What has not been presented so far in this paper is the data concerning students' success in the overall course assessment. The correlation between approach to learning and success is notable: The five students who were shown to have primarily used a conceptual approach throughout the course passed, and the others who didn't failed.

## CONCLUSION

The initial findings of the larger study regarding students' approaches to learning and metacognitive development have been added to significantly, we would argue, by the present analysis of students' responses to conceptual probes. In this paper we have only presented the findings from the data using the recycle system probes, elsewhere we have analysed the data from other probes used in this study (Case, 2000). We maintain our position stated earlier that it is more appropriate to identify constructs such as approach to learning as they manifest in particular contexts, than to impose prior categories on the data. Our major motivation in this regard is to yield an understanding of student learning which can be used to improve teaching and learning in real contexts such as these.

Following from this point we need to question the utility of these findings. We have identified different approaches adopted by students who are exposed to the same course context, some approaches of which are significantly more successful than others. Why did some students adopt a conceptual approach while others clung to an information-based approach even when they repeatedly failed course assessments? We think that Ramsden's (1988) work outlining the importance of perception points to a potential explanation of these choices, and our current work is seeking to uncover in more detail how individual students' perceptions of the course influenced their approaches and ultimate learning outcomes.

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