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Investigating the Effectiveness of Animations in Exploring Learning: A Case Study in a Chemical Engineering Course



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Thesis submitted in fulfilment of
Master of Science

In the Department of Chemical Engineering

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Abstract

Using technology in the classroom environment has become increasingly popular among educators. One way of employing technology is using instructional animations to teach concepts, favoured owing to their ability to depict changes in object over time. Animations are commonly believed to increase motivation and foster learning, but there is little empirical evidence for this belief. Some researchers have found that animations can be effective; others, however, show that animations have the same effect as a combination of static pictures and text. Some have even showed that animations could actually have negative effects on student learning.

A lecturer at the University of Cape Town had planned to use animations in his third year undergraduate Chemical Engineering Course in Reactor Design. This became the context for the present study which investigated the effectiveness of these animations for promoting conceptual understanding as well as exploring students' perspective on learning from animations as well as students' enjoyment level. A quasi-experimental case study was conducted over four topics in Reactor Design and one topic was repeated. Each investigation was on one topic, and in each investigation, the Reactor Design class was split so that the student either attended a traditional lecture or an animation lecture. The two groups of students were used to compare the impact of animations on student learning.

Students' prior performance was estimated using their second-year core-course marks as a baseline. The baseline showed that in four out of five investigations, the two groups were equivalent. However in the final investigation, the students in the traditional lectures achieved higher baseline scores than their animation counterparts. Three of the investigations showed, using a t-test analysis on the post-test marks, no statistically significant difference between the effectiveness of animations and traditional lessons. The remaining two animations showed that these were less effective than their traditional equivalences. The overall results across all five experiments, using a multivariate analysis, showed that students who attended the animations did significantly worse than students who attended a traditional lecture, with an average mark of 3.95% lower.

However, the students who attended the animation lectures reported that they enjoyed the lecture more than the students who attended the traditional lecture. This result is possibly due to a novelty effect that makes students find animations more interesting. Another important result was that the students' perspective on their own understanding of the contents was higher in the animation group compared to that of the control group. However, this was at odds with their actual marks in the

post-test. This confusing result could be due to the fact that students were participating in an experiment that leads to them thinking positively about the effects of the intervention. This is commonly known and referred to as the Hawthorne effect.

In conclusion, the use of animations in a classroom environment has been explored and it shows that innovations may have some benefits but researchers need to think carefully about what they are trying to do when introducing animation into an educational context. It is thoughtful teaching that will make the difference to a student's overall learning process and not the medium which has been chosen.

University of Cape Town

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1. Introduction

1.1. Animations

Humans have always needed some sort of medium to convey their inner thoughts to another person. The other person can form an understanding of the information by using their eyes and ears. When one person speaks, the other person must be able to know that same language to understand this information. Likewise, a person can record information for another person to view it later. External representation can use a physical medium to convey information to others. These mediums can include: papyrus, developed by the Egyptians; paper, invented by the Chinese; and even cave walls used by Bushmen for their paintings. Some of these old mediums are still being used today.

As technology developed further, so did the number of available mediums. Today, the most popular technology is to use a form of multimedia as an attractive way of conveying information. Multimedia can be a combination of images (still or moving) and/or text and/or sounds and can be interactive. Animation is a combination of all these aspects.

The concept of combining images and text is not new (Large, 1996). In education, texts were added to images (such as graphs and charts) to explain the image. In the same way, pictures were added to text for a specific function which can include attracting the readers to the text or using a different way of representing the same information. As animations can accommodate all these abilities, many educators commonly seem to think that animations are the answer to facilitating effective learning (see, for example, Chandler, 2009; Hegarty 2004; Large, 1996; Lowe, 2003). This belief is fuelled by developers constantly marketing their technology in such a way that it seems to be the answer for everything (Hegarty, 2004).

The empirical evidence for educational animations' effectiveness does not strongly support what its developers are claiming. In many of these studies, researchers compare a group of students who have attended an animation and compare their level of understanding to that of another group of students who have seen an animation equivalent (usually a combination of static pictures and text). Across many different educational contexts, the results have been mixed (See Tversky et al., 2002 or Höffler & Leutner, 2007 for meta-analyses).

1.2. The study

This study took place in a context where a Chemical Engineering lecturer from the University of Cape Town decided to introduce some innovation in his course, Reactor Design for third year Chemical Engineering students. This course has a reputation for involving complex concepts and difficult processes and lays an important foundation for Chemical Engineering design work in a typical industrial plant.

The objective of this study was to develop animations for the Reactor Design class and to conduct tests to determine whether animations can facilitate learning. The three key questions in this study are as listed:

1. Does the use of innovations better facilitate student learning?
2. Will the students enjoy animation more than a normal lecture?
3. What are the students' perspectives on learning with animations?

This type of study is classified as a quasi-experimental case study. For this study, there are five investigations, and each focuses on a different topic in Reactor Design, with one topic repeated.

1.3. Overview of thesis

The remaining chapters are organised as follows: Chapter 2 starts with a background to images and text to serve as some history behind animations. Thereafter, it reviews animation effectiveness in education. Finally the chapter concludes by reviewing some cognitive theories that will help develop an effective animation. Chapter 3 describes the context of where the study was conducted with details on how the course ran. Chapter 4 will give some brief insight as to how the animations were developed. It will show the cognitive theories were used in these animations. Chapter 5 discusses the data collection and analysis methods being used in the case study. Chapter 6 presents the results of the study. Chapter 7 presents the findings to address the key questions in the research study. The final chapter offers concluding remarks about the study and future research.

Appendices include supplementary information on the course, the questions from the post-test and questionnaires. It also includes a CD with screenshots of all the animations and an example of animation used in the study.

2. Literature review

2.1. Text, static and dynamic visuals

It is well-known that text and pictures have been used to record information throughout the ages. Ancient Egyptians and Chinese civilisations were among the first few who used pictograms, which were first developed around 3150 BC and 2800 BC respectively, to record information. Thereafter, the Phoenicians used the Egyptian hieroglyphics to make their own alphabet. The Greeks adapted the Phoenicians' alphabet to make their own, which was later replaced by the Latin alphabet which forms the basis of today's modern English alphabet (Ostler, 2006). According to Large (1996) the addition of pictures to accompany text only became a common practice towards late 1300s.

2.1.1. Text and static visuals in education

Educators generally use pictures to accompany text. Pictures are able to portray spatial relations of objects using space (Tversky et al., 2002), where text would have to use many words to describe the same spatial relations (Large, 1996). Pictures, however, also have the capacity to represent information that has no relation to space (Tversky et al., 2002). Rieber (2002, p2) states that there are three main types of visuals within text: "Representational, analogical and arbitrary."

Representational visuals represent a portion of the elements within the written concepts to reinforce the text's content (Large, 1996; Höffler & Leutner, 2007). Graphics can also be used to provide more information than the text itself (Large, 1996; Tversky et al., 2002). Representational graphics are the opposite of decorative graphics (Höffler and Leutner, 2007) which have no relation to the text (Levin, 1981) and do not provide learning benefits (Large, 1996). Representational graphics can be anything that look like that object itself or is visuospatial (Tversky et al., 2002). A few examples include maps, schematics and photographs (Rieber, 2002; Tversky et al., 2002).

Rieber (2002) compares analogical graphics to metaphors or analogies, where there are certain characteristics that are similar, but the characteristics are not the actual concept. Metonymy is a good example where associative symbols are used for the object (Tversky et al., 2002). For example in computers software, the Windows recycling bin symbol is used for recycling but the recycling of computer files does not involve plastic bottles, tins or paper. However, it does represent that recovery is possible for a deleted file. Analogies can be used for novice students to act as a foundation for learning the actual concept itself, or used to explain abstract or complex concepts (Tversky et al., 2002) or even invisible phenomena (Hegarty, 2004). For instance, chemists use ball-

and-stick models to represent atoms and the chemical bonds between them (Jones et al., 2005). However, the ball-and-stick model does not represent all of the concepts that are needed to fully understand molecules. Thus, one needs to know the limitations of analogical graphics and be careful when using them. While they can be a great tool to enhance learning, if not used correctly the benefits can backfire and cause confusion and misconceptions (Rieber et al., 1996; Rieber, 2002).

Lastly, Rieber (2002) describes that arbitrary graphics which are not representational or analogical, but in contrast to their name, they are actually more 'organisational' (Levin, 1981). The so-called 'arbitrary' graphics add structure or logic to text (Levin, 1981) allowing the non-spatial explanations to be represented in a spatial format (Tversky et al., 2002). Examples include bar charts, flow diagrams and line graphs (Rieber, 2002; Tversky et al., 2002).

2.1.2. Animations versus pictures

Animations, a type of dynamic graphics, are expected to be able to do the same functions as normal static graphics and, additionally, explicitly show temporal and positional changes (Morrison et al., 2000). In essence, animations are just "simulated motion picture[s]" (Mayer and Moreno, 2002b, p88). It is a picture as it is a visual that contains at least one element that is not alphabetical or numerical (Large, 1996). Animation is a motion picture as it is a sequence of still pictures that follow each other, which can be perceived as continually changing (Rieber, 2002). Animation is 'simulated' as it has objects that are artificially rendered (Mayer and Moreno, 2002b, p88), which is different from a video motion picture.

Generally, there are three ways for animations to show changes for objects by means of as follows: "transformation", "translations" and "transitions" (Lowe, 2003, p159). Transformations are changes with regard to the appearance of the object such as colour, size or shape. Translations are changes in the position of the object over time, and are able to depict trajectory (Rieber, 1991; Tversky et al., 2002). Lastly, transitions are changes in presence or absence (partially or fully) of the object on the screen.

As pictures are naturally able to portray visuospatial information using space, this can be extended to animations which can also portray changes (Tversky et al., 2002). They should be effective in topics where change and trajectory are needed (Rieber, 1991; Tversky et al., 2002). However, even though animations are essentially pictures in series, it has been claimed that the way that students learn from animation is different to that of static visuals (Mayer and Moreno, 2002b).

2.2. Animations and their rise in popularity

The use of animations in education has increased due to the availability and affordability of personal computers (Goldman, 2003), making animations increasing popular for educators (Rieber, 1991). It is often believed that animations are able to facilitate learning better than static pictures (Tversky et al., 2002) as animations, after all, are an extension of static pictures (Mayer and Moreno, 2002b).

Animations have a perceived reputation of being able to “benefit comprehension and learning, and foster insight” (Tversky et al., 2002, p247). This ambitious promise has actually been made for almost every new technology that can be applied to education (Hegarty, 2004). The fact that animations have the ability to show temporal and spatial information explicitly is what draws educators to use this kind of technology (Tversky et al., 2002). However, as with each new technology introduced, students tend to be marvelled by its novelty, thus can be more motivated to learn from it (Hegarty, 2004). As Workman (2004, p518) points out that “learners who are motivated [...] tend to learn more than those who are not”. However, if animations are overused, the novelty effect is likely to wear off and thus conservative use of animations should be considered (Large, 1996).

Despite the ‘hype’ of using animations, empirical evidence shows mixed results about the effective use of animation in education (see Tversky et al., 2002 or Höffler & Leutner, 2007 or Ploetzner & Lowe, 2012 for meta-analyses over a variety of different studies) and does not back up the promise of information delivery for effective learning. While, some studies have shown that animations can be more effective (eg. de Koning et al., 2010a or Spanjers et al., 2011), others generally show no differences between the effects of using static visuals and animations (eg. Moreno, 2004 or Kriz and Hegarty, 2007) and some even have results of negative effects on learning when using animations (eg. Scheiter et al., 2006). This means that developers and educators should approach this assumption, that animations are better than static visualisations, with great caution depending on the topic which they wish to convey (Lowe, 2003).

2.3. Evidence for the educational effectiveness of animations

As noted above, there is mixed evidence regarding the educational effectiveness of animation. This range of mixed empirical evidence brings on a variety of possible explanations. Meyer et al. (2010, p136) offer an explanation that the “nature of the learning material” is what gives rise to different results in different settings. Ploetzner and Lowe (2012) further agree that because there are so many

topics; it is hard to compare studies across different fields and generalise the results. Not all topics are equally suitable for the use of animations.

Lowe (2004) offers another interpretation of these results which states that animations can “overwhelm” or “underwhelm” students. Watching animations can be considered to be quite a passive type of learning; it can be quite easy to underwhelm the student, thus the student does not engage with the content sufficiently. Alternatively, the amount of content and the complexity can be too much for the student to understand (i.e. requiring too much cognitive processing) which causes insufficient memory resources to process the information and the student to be overwhelmed.

Tversky et al. (2002) suggests that a possible interpretation of the studies which have shown that animation delivers better learning outcomes compared to text and static images, is that the animations portrayed more information than text and images. An example that Morrison et al. (2000) noted that as an animation is continuous and furthermore shows all the steps of development, but in the static and text equivalent, the student has to infer from the information provided.

Sometimes there is no effect on learning between animations and static learning (Morrison et al., 2000). This is maybe not surprising as animations are a form of representing the same information in a different manner.

However when animations were unsuccessful at promoting learning, it is possible that they were used for decorative purposes and not for representational purposes (Weiss et al., 2002; Höffler & Leutner, 2007). Decorative animations cause a distraction from the actual information and means the learner has to search for relevant information. It has been empirically confirmed by Höffler and Leutner’s (2007) meta-analysis that decorative animations have negative learning effects.

Tversky et al. (2002) argue that complex process animations can be difficult to perceive. As an example they discussed that the motion of a galloping horse was incorrectly represented until photography was invented. This means that if students that view a very fast animation, they could perceive the information incorrectly.

Another possibility for failures in animations is that animations are transient (Lowe, 2004; Chandler, 2009). Animations do not present all the information permanently, and over time the information changes. The viewers need to keep up with the information change but if there is too much information presented at any one time, then the student will miss some information and might not be able to construct an overall understanding of the concept.

Given the mixed evidence for the educational effectiveness of animations, it is worth considering whether one can justify the large difference of effort and time spent making the animation compared to the static visuals (Chandler, 2009; Höffler et al., 2010).

Studies on animations are still being conducted, but now the focus has turned to how animations can facilitate learning (Chandler, 2004). This is to accommodate the assumption that the way students learn and process information from animation is different to that of static visuals (Tversky et al., 2002). Instead of just generally comparing animations and pictures, theories have been developed to understand how students learn and from which aspects of the animation, in order to develop animations in such a way that they can be used to their best potential (Hegarty, 2004). These theories are reviewed in the section that follows.

2.4. Cognitive theories

A large number of cognitive theories have been developed (see Reed (2010) for a review on multiple cognitive theories) to build an understanding of how animations and static visuals might influence learning (Höffler & Leutner, 2007). Insights into cognitive architecture and processes (Chandler, 2004; Kalyuga, 2009) can be used to design animations to facilitate student learning. Popular theories used in multimedia development include Sweller's "Cognitive Load Theory" (Sweller et al., 1998) and Mayer's "Cognitive theory of Multimedia Learning" (1998), and these are briefly outlined in what follows.

2.4.1. Cognitive Load Theory

Cognitive load theory was initially developed in the 1980s by Sweller (Van Merriënboer & Sweller, 2010). It explores the limits of working memory (Baddeley, 1992) and gives guidelines on how information can be presented in such a way that it will not "overwhelm" or "underwhelm" student's processing requirements (Lowe, 2004). Working memory is the short-term memory in the brain that is able to hold visual and verbal information until the information can be processed (Baddeley, 1992).

Information can be stored in the long-term memory. Schema is the element held in long-term memory that organises and holds information (Pollock et al., 2002; Sweller, 2002; Van Merriënboer & Sweller, 2010). Schemas can be constructed when new information is presented and can integrate the new information with the existing information (Sweller, 2002).

By drawing on schemas, one is able to combine information stored in long-term memory with the information in working memory. One can construct schemas to consciously store in long-term

memory (Sweller, 2002). Many simple schemas can be built up into one complex schema which can be treated as one element (Van Merriënboer & Sweller, 2010). With more practice and repetition, schemas can be automated and in time it will require less effort to use them.

There are three type of cognitive load: extraneous, intrinsic and germane (Van Merriënboer & Sweller, 2010) and these explain the limits of working memory and schemas. Wouters et al.(2009, p2) describes these as follows: “Intrinsic load is related to the complexity of the domain,[...]. The load imposed by information and activities that hinder the learning process is called ‘extraneous’, whereas the load related to information and activities that foster the learning processes is called ‘germane’ ”. It should also be noted that intrinsic and extraneous load are additive within the limits of working memory (Van Merriënboer and Sweller, 2010).

Intrinsic load (i.e .the nature of the animation content and its complexity) is determined by the number of elements interacting with each other (Van Merriënboer and Sweller, 2010). As animations are transient in nature (Tversky et al., 2002), it thus imposes some memory requirements from the student as the student has to keep the previous piece of information in their working memory while viewing the next piece of information. If the animation has too many elements interacting in the same space at one time, it can cause overloading of information in the working memory. For instance, this can be controlled by presenting one piece of information at a time, thus lowering the memory requirements.

On the other hand, extraneous load is determined by the format in which the developer chose to design it. It does require some processing from the student, but unnecessary information does not facilitate learning and thus reduces working memory. By reducing extraneous cognitive load, the student can direct their focus on learning. In animations, students need to split their attention to different areas of the animation to find relevant information. An example would be the text and animated object being placed far apart from each other. Since the student can only see one part of the screen at a time, they have to split the attention to both parts of the screen (Rasch and Schnotz, 2009).

Germane load is determined by the how information is automatically constructed, structured and organised. One wants to promote the use of germane load so that the student can learn from animations. This means that it is best to first select and then sort out the important information to construct schemas that will relate to other pieces of information (Pollock et al., 2002; Sweller, 2002).

One can use worked examples to ensure that students know how the information fits in a worked example context (Sorden, 2005; Van Merriënboer & Sweller, 2010).

Animations are able to communicate spatial and non-spatial information through spatial properties as well by depicting a trajectory (Tversky et al., 2002). It has been suggested that they are able to accommodate those students who struggle to imagine processes by providing an external process (Salomon, 1979), thus also reducing their cognitive load (Meyer et al., 2010). However, at the same time, as animations are transient, it has been noted they actually might demand a higher cognitive load to process the information displayed (Hegarty, 2004; Canham and Hegarty, 2010). For effective learning, the extraneous load must be reduced, the intrinsic load must be managed so that not too many elements are presented at the same time and the germane load must be increased (Pollock et al., 2002; Sweller, 2002; Van Merriënboer & Sweller, 2010).

2.4.2. Cognitive Theory for Multimedia Learning

Mayer's "Integrative Model of Multimedia Learning" (1999) theory is based on three basic assumptions to explain how problem-solving transfer can be used in multimedia, summarised by Höffler and Leutner (2007, p723) as "active processing", "dual channel processing and dual coding" and "limited capacity". As this theory applies to all multimedia theory, it can be adapted to what is relevant to animations.

Active processing drawn from constructivist learning theory, describes an activity where students will process information by actively selecting the appropriate information, organising and integrating that information with prior knowledge (Mayer, 1999; Mayer & Moreno, 2002a).

Dual coding is drawn from Pavios's dual coding theory (1986) where the visual and the verbal channel are processed separately. The processing of each of these channels has different working memories (Baddeley, 1992) thus verbal and visual information are processed differently.

Limited capacity refers to the working memory of visual and verbal systems (Mayer, 1998). If too many elements are processed at any one time in either visual or auditory memory, it can overload the system and cause some elements not to be processed (Mayer & Moreno, 2002a; 2002b).

These assumptions form the basis of the "Integrative Model of Multimedia Learning" (Mayer, 1999) and are summarised in Figure 1.

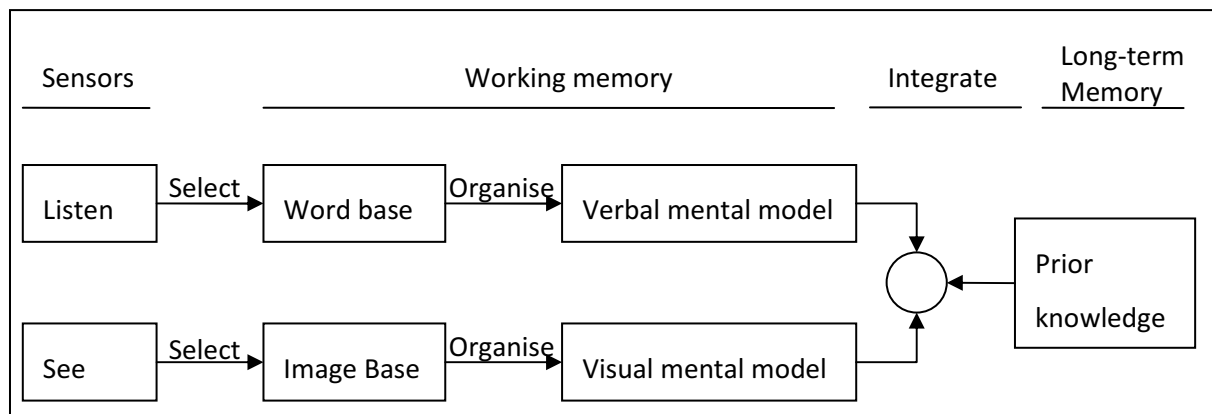


Figure 1: Mayer's Cognitive Model of Multimedia Learning (1999) - Adapted

2.5. Principles for design

Since the working memory has restrictions, it is thus important to make sure that the working memory is not overloaded, to ensure efficient use of the limited space (Chandler, 2009). But at the same time, it is also important to keep the student sufficiently engaged to ensure the student is not underwhelmed. Underwhelming happens when the student does not engage enough with the subject material and does not learn the expected learning objectives. Another restriction to working memory is that the memory can only be held for short periods of time.

Animations are believed to be able to promote comprehension and problem transfer (Höffler et al., 2010). Therefore, it has been suggested that the best use of animations is to clarify concepts and represent information (Weiss et al., 2002). Rieber (2002) states that animations should be representational of the concept and that the animations created must be suitable for the students trying to learn the concept. Weiss et al. (2002) urge developers to use animations to teach complex concepts, invisible systems that cannot be seen with the naked eye, concepts that change with time or procedures.

Below, a summary on the inherent problems with animations and the principles that can be used to improve learning from animations is presented. Generally, most of the case studies that were mentioned in this section are based on students that were attending university or college. The only exception to this rule is the Wouters et.al. (2009) study which involved high school pupils.

2.5.1. Choosing between different modes of conveying information

Animations are able to accommodate two forms of information: words and graphics. With the vast number of options to present these two forms of information, any animation can be created. With so many choices offered to the developer, what the developer chooses might not be beneficial to

student learning. Thus, several principles have been developed to suggest better choices for the two modes of information that can be used to accommodate learning.

Present with words and pictures vs. words by itself

Dual-coding theory means that there are two modes of presenting information which could be advantageous to a learner as he or she can choose the mode of information at which he or she is more adept (Large, 1996).

If one is using multimedia, one is assuming that two modes of presenting information surely are better than using one mode of presenting information (Mayer, 1999), otherwise, there is no point in using multimedia. Höffler et al. (2010) agree with Mayer that a combination of both modes of information will promote “comprehension and problem transfer”. Mayer (1999) has summarised findings between Pavio’s (1986) dual-coding of delivering information comparing it to uni-coding. He concludes that students learn better from graphics and text which are better than text by itself.

Extraneous material excluded vs. included

Before presenting information, it is important for the developer to distinguish between which information is needed and that which is not. Extraneous material is any material that is not part of the essential information that a student requires for learning the topic. It can cause extra cognitive processing, in addition to the essential processing, which could possibly cause the learner to be overwhelmed by the information that he or she is presented with. In the end, extraneous information will hinder the learning process.

Thus, by taking out the extraneous information, the developer has “weed[ed]” (Mayer & Moreno, 2003, p48) out all the extra information, and will be able to force the student to focus only on the relevant information. Effectively, taking out extra information will be more beneficial to learners than putting in extra information (Mayer & Mareno, 2010).

Present words as narration only vs. present words as text and narration

A developer has to choose whether to present word information as narration or as on-screen text, but there is no rule to say that the developer cannot present the same information with both narration and on-screen text. By presenting both forms of information, it is assumed that the student now has a choice selecting between narration and verbal information to suit their preferences.

However, Mayer and Moreno's research (2003), on presenting the same information as on-screen text and narration, states that equal information should not be presented twice in different ways. As mentioned before, presenting text on the screen along with graphics could overwhelm working memory and cause a split attention affect (Mayer & Moreno, 2002a).

This effect is caused by identical information being presented in verbal and visual forms, is called the redundancy effect. When there is too much on the screen, it can overload the visual working memory. When visual working memory is overloaded, there are less cognitive resources to make connections between the verbal and visual channels. The student could also miss relevant parts of the graphics while they are reading information on the screen.

Words presented as narration vs. words presented as on screen text

The student may take a considerable amount of time to read the text depending on the length of the text. For an average adult, he or she can read up to 240 words a minute for comprehension (Schmidt-Weigand et al., 2010). This is especially a problem in animation, where the information is transient, where the student could easily miss out the important information because they are focusing on the text and especially if the student's reading pace is slow.

Detection of eye movement has been used to determine the effect of the displayed information. This type of experiment will determine where students look on the screen. Using this information, one can decode the eye movement to see which aspects of the screen the viewer is focusing on. Generally, humans can only focus on one part of the screen at a time. Thus having too much visual information on the screen causes a split attention affect, where the viewer's focus is split to look in multiple places at once.

It has already been noted that there are two channels to process information. By converting the words on the screen (i.e. part of the visual channel) into narration (i.e. the auditory channel), it is possible to offload some of the visual information which could be an overload. As each channel has limited resources, by offloading from one channel to another, some visual cognitive memory resources can be freed up. The students will be able to view the displayed information while listening to corresponding relevant verbal information. Mayer (1999) calls this the modality effect.

In Ginns' (2005) study, he confirms Mayer's modality effect using a meta-analysis. Ginns analysed 39 studies and concluded from these studies that presentation with graphics and narration performed better than presentation with graphics and displayed text.

It is interesting to read and note in Schmidt-Weigand et al.'s (2010) study, that when students view animations, they tend to opt for reading the words first before finding the corresponding graphics to examine. It is possible that the students are conditioned to read tasks first, before trying to solve a problem or a task.

2.5.2. Addressing the split attention effect

As been mentioned before, there can be a risk of overloading of information in either the visual or narrative channel. For instance, the visual split attention happens when there are two sources of information displayed on the screen at the same time. On the other hand, auditory split attention happens when two sounds are projected to be listened to at the same time.

The most common problem is the visual split attention as opposed to auditory split attention as extra sounds, such as music in the background, can be easily eliminated. On the other hand, visual split attention is a more inherent problem as the viewer has to select and process different areas of a display simultaneously. Split attention is a source of extraneous load where the student has to select information that is presented at the same time in order to construct a mental model (Wouters et al., 2009).

However, visual displays have more options to convey essential information than narration does. One can display information with both graphics and words with multimedia. Furthermore, there are two ways to present word information: on-screen text and narration.

Word placement near the relevant graphics vs. far away from relevant graphics

As discussed, on-screen text can be converted into narration to help offload some visual information, although shorter sentences can still be used as long as this does not overload the visual channel (Mayer & Moreno, 2003). However, as with all displayed information, the choice between narration and on screen text should be considered as it could cause a split attention affect.

If one chooses to include text as part of the display, then placement of text is crucial. Mayer and Mareno (2003) call this a "spatial contiguity effect". It is important to note that a human's viewing is limited and can only focus on a small area at any one time (de Koning et al., 2010a). By aligning words and graphics on the screen, less cognitive resources will be spent on searching for information. The student will still have to retain one piece of information while trying to find the other piece of information to integrate it together, but this time lag will be short. Thus, the student will not have to keep a particular piece of information for too long and in turn hinder learning. Scanning for relevant

information takes up cognitive resources, thus by reducing the need to search for information, it is possible to free up some more cognitive resources that could be used to process important information.

Wouters et al. (2009), Florax and Ploetzner (2010) and Schüler et al. (2011) have all done case studies on the effect of placing text near graphics. By ensuring proper text placement with text closer to the relevant graphics, more effective learning outcomes are noted.

Presenting animations and text (verbal and written) simultaneously vs. successively

Split attention does not only happen on the screen, but also happens over time (Ginns, 2006). This happens when the corresponding information is not presented at the same time and the student has to wait for the necessary information to integrate information. Not only must the student be able to select, organise and integrate information, the student also must be able to hold information in working memory for certain time periods so that the piece of information can be processed later.

If the information is held too long in the working memory and there a need to process other information while having to hold this piece of information, this could easily overwhelm the student. Retaining information requires more working memory and this means that cognitive processing is even more limited than before. The reason why students need to hold pieces of information is that sometimes this particular piece of information needs some other piece of information to make a coherent understanding.

By presenting pictures and the corresponding words at the same time, the amount of information that needs be held in the working memory can be reduced. Mayer calls this principle the “temporal contiguity effect”, where corresponding graphics and words should be presented simultaneously. Thus, the student does not have to wait to process information and thus waste precious cognitive resources.

Ginns' meta-analysis (2006) identifies temporal contiguity effects as a source of extraneous cognitive load. This means that presenting information successively could impair learning. However, as long as the time lag between corresponding pieces of information is less than seven seconds as suggested by Baggett (1984), the same results can be achieved as with simultaneous presentation. This study was conducted done over 334 college students on 7 different videos.

Fewer interacting elements vs. too many elements on screen

As humans have limited working memory, the researcher also needs to limit the number of elements that are presented to the student on the screen. A good rule of thumb is Miller's (1956) magic "seven plus or minus two" rule which is applicable for multimedia (Baddeley, 1994, p353). This means five to nine interacting elements on screen is good for students' engagement with the animation information (Ginns, 2006; Van Merriënboer & Sweller, 2010).

Segmented vs. continuous information

When too much essential information is presented on the screen, the student can be easily overwhelmed in both visual and audio channels. This happens when there is too much information that needs to be processed and attended to, and the working memory cannot keep up with the cognitive demands. Thus, the student will not be able to process crucial information (Mayer and Moreno, 2003).

A solution to continuous information is that information can be broken up into smaller pieces so that it is presented as segments to the student. In this way, the student will have some time to catch up the processing demands and, furthermore, it will help the student to finish one concept before a new concept is introduced. Smaller chunks of information are easier to process and require less mental effort as compared with longer pieces of information.

2.5.3. Dealing with the transient animations

Animations are different from traditional forms of media, where text and images can be revisited multiple times afterwards as the information is permanent (Höffler et al., 2010). Animations are transient in nature meaning the information appears and disappears with time. The student has to be able to view the information at the right time to be able to process and integrate information.

As animations have transitions, the student needs to keep this information in working memory to ensure effective learning. Students need to process the information while it is being delivered for effective learning, otherwise crucial information may be missed as time passes by. As human beings, we are only able to focus on one part of a display at any one time (de Koning et al., 2010a). Therefore, animations should be designed in such a way that the students' attention can be diverted to the appropriate information in the available time that it is offered.

Animation speed

The temporal structure of an animation (i.e. its speed), as well as the perpetual load (i.e. how much one can see at any one time), plays an even larger role than the visuospatial role (Meyer et al., 2010). According to Zacks and Tversky (2001 as referenced by Meyer et al., 2010), there are two hierarchical sub-parts to the temporal structure: the macro-events and the micro-events. Macro-events are the general events that are built up of many micro-events. For example, making a cup of tea can be a macro-event. But, boiling the water, putting the teabag in the cup, adding the boiling water, adding sugar and milk and stirring with a spoon are all micro-events and they make up the macro-event of making a cup of tea.

Meyer et al. (2010) and de Koning et al. (2011) have performed case studies on the importance of the speed of an animation. In both of these case studies, the presentation speed varied but the amount of content stayed the same (i.e. seeing the effect of a number of elements processed in a unit of time is different). Student's eye movements were detected and recorded. de Koning et al. (2011) argue that if the time spent on the task is longer, more time will be available for processing, thus leading to a better result. Generally, students with low prior knowledge preferred the low speed animations. According to Meyer et al. (2010), high speed presentation is more effective for learning for macro-events and low speed presentation is more effective for micro-events.

Thus by varying speed throughout the presentation to focus on micro and macro events, more effective learning from animations should occur. In other words, slowing down on micro-events will allow student to see and process the short duration of the micro-event. And by hastening the macro-events, students will be able to build up on the micro-events to make a mental model of the macro-event.

Cueing

To process relevant information, the student must be able to find the relevant information in the timeframe that they have been given. In order to reduce the information that needs to be held in working memory, the student must be able to select the visual information so that he or she can integrate it with the verbal information without having to hold either form of information in working memory for too long (Tversky et al., 2002).

Visual split attention effect is also a problem: the student could be looking at important parts of the display but if it is not relevant to the topic at hand, the student could be missing vital information. Highlighting and giving cues is a way of guiding the student to the correct parts of the display and

thus the student does not need to spend time trying to find the correct information on the screen and overloading the visual working memory.

Visual cues can vary in the way they are presented. They cause the student to look at certain parts of the display by bring their attention to a particular area. Examples include: presenting arrows, highlighting (using contrast), flashing and by making one element larger than the others.

The following authors all conducted studies that made explicit use of animation cues: Kriz and Hegarty (2007); de Koning et al. (2010a, 2010b, 2011); Lee and Shin (2011). These animations were developed for toilet mechanics, the cardiovascular system and the internal combustion engine respectively. Detection of eye movement was only used for the 2007 and 2010 animation studies. Kriz and Hegarty (2007) and Lee and Shin (2011) used arrows whereas the De Koning et al. (2010a, 2010b, 2011) studies used luminous contrast.

De Koning et al. (2011) found that cueing will improve inference, comprehension and transfer; however multiple cueing will direct the student's attention to the appropriate area (De Koning et al., 2010b), but will not necessarily mean the student will be able to make connections between the cues (De Koning et al., 2010a). On the other hand, Kriz and Hegarty found that visual cues will guide the student's attention, but did not improve student results. Lee and Shin (2011) showed that student with low spatial ability preformed better with cues than without, and that cueing with motions did not improve learning.

Thus, in line with cognitive theory, it is possible to use cues to reduce memory working requirements. Learners definitely spent more time looking and viewing the cued information than if it were none (de Koning at al., 2010b). However, Kriz and Hegarty (2007) found that cueing was not effective as it could guide the student attention, but not necessarily lead to understanding. However, if the system is too complex and has too many procedures, it could be a problem in itself which even cueing cannot overcome. Lee and Shin (2011) showed positive results with cueing and that it should be used especially in the case of low spatial ability learners so that they do not need to spend as much time finding the correct information. De Koning warns that one type of cueing is not the same as another type of cueing, and that one cannot generalise the type of cueing.

Interactivity

It is known that interactivity, on its own without the use of animation, facilitates learning (Tversky et al., 2002). When the student views an animation, the student's learning is generally passive. Thus, by

adding interactivity to animation, it could make the viewer more active (Large, 1996). Interactivity in animation could be used for a variety of options to enhance learning: to control the pace and view of the animation, to manipulate parameters within the animation and to navigate the system for alternative operations (Moreno & Mayer, 2007).

As previously mentioned, controlling the pace of the animation allows the student to focus on different concepts of the display. By manipulating the variables, the student can see the outcomes of changing the variable; this is a form of prediction. Prediction is known to facilitate learning as the student is able to check whether their predicted outcome is correct or not (Morrison et al., 2000; Tversky et al., 2002). Navigation allows for stopping, playing and rewinding functions, which can allow the user to re-inspect different aspects of the screen.

However, including interactivity within the animation means that there needs to be an interface. By having interactivity, the interface itself could require cognitive resources which could be used for learning (Rasch & Schnotz, 2009).

Studies done by Rasch & Schnotz (2009) and Moreno & Mayer (2007) explore the difference between interactive and non-interactive animations. Rasch & Schnotz's (2009) study involved navigation and Moreno & Mayer's (2007) study involved photosynthesis in science. Both investigated animations that included interactivity for the learner to use. There was no significant difference between interactive and non-interactive in the first study and in the second study, the result was inconclusive and required further research.

2.6. Summary

As noted here, there is mixed evidence on the effectiveness on animations. Thus, for the present study, principles from cognitive theories such as Cognitive Load theory and Cognitive Theory of Multimedia Learning have been used to guide the development of the animations. The most important aspects taken into account were: the mode of information to choose, the split attention effect and transience.

3. The Context of the Study

3.1. Introduction

This case study took place in the context of the Reactor Design course in the undergraduate programme in Chemical Engineering at the University of Cape Town (UCT) during 2010 and 2011. In order to understand the context of the study, information about the university will first be provided. Following this, an introduction to the Chemical Engineering Department and its undergraduate programme will also be provided.

3.2. University of Cape Town

The University of Cape Town (UCT) is located in Cape Town, South Africa. The university was first founded in 1829 as the South African College. In 1918, this college was formally recognised as an university (University of Cape Town, 2012a). Today, the university is still growing in number with just over 17 000 undergraduates, over 7 500 postgraduates and 5 442 staff members including 982 permanent academics in 2010 (University of Cape Town, 2012b).

UCT is internationally recognised for its academic excellence and its determination to keep on striving to become better. Not only is UCT rated the best university in South Africa, but is also considered to be one of the best African universities. In 2011, it was rated as 103rd in the world by the Times Higher Education World University Rankings (TSL Education Ltd., 2011), 156th by the QS World University Rankings (QS Quacquarelli Symonds Limited, 2011) and within the top 300 by the Academic Ranking of World Universities (ShanghaiRanking Consultancy, 2011).

3.3. UCT's Chemical Engineering Bachelor Degree

UCT has six faculties: Commerce, Engineering & the Built Environment, Law, Health Sciences, Humanities and Science (University of Cape Town, 2012a). The Chemical Engineering Department falls under the Faculty of Engineering & the Built Environment.

The Department of Chemical Engineering is the largest in South Africa and has produced almost a third of South Africa's Chemical Engineers (University of Cape Town, 2012c). The Chemical Engineering degree from UCT is recognised by the Engineering Council of South Africa (ECSA) and meets international standards; thus, the degree is recognised by the Washington Accord signatories. The Department of Chemical Engineering takes in approximately 120 undergraduate students each year.

UCT's Bachelor of Science Degree allows a minimum of four years and allows a maximum of six years for completion of study. The first year of study starts with the basics of mathematics, sciences and technical drawing. Second-year students are exposed to more Chemical Engineering theoretical studies, advanced mathematics and chemistry as well as a Chemical Engineering practical course. Almost all the third year courses consist of chemical engineering theory with an exception of numerical methods and practical coursework. By their final year of study, the focus has shifted to theories being applied to the real world and a final year design course is where all knowledge from previous courses must be utilised to design an industrial plant (University of Cape Town, 2012d).

3.4. A closer look at the Reactor Design Course

3.4.1. Third year Chemical Engineering students

The Department of Chemical Engineering expects a typical Chemical Engineering student to spend 50-60 hours each week on coursework. By the students' third year of study, it is expected that the third year student should be spending at least 20-30 hours a week on self-study.

The Higher Education Qualifications Framework credits or HEQF credits are a standard of how long a student is expected to spend on the degree (Department of Education, 2007). Each credit equals 10 hours of study. A third year Chemical Engineering student is assigned 124 credits which mean 1240 hours should be spent on studying inside of class and self-studying.

Reactor Design is split up into two courses with one for each semester: Reactor Design I and Reactor Design II. The HEQF credits for Reactor Design I is 12 credits while Reactor Design II is 13 credits. In the first semester, Reactor Design I runs alongside the following courses: Thermodynamics II, Chemical Engineering lab (a full year course), Mass Transfer and Numerical Methods. In the second semester, Reactor Design II, runs alongside these following courses: Solid Fluid operations, Chemical Engineering lab, Separation Processes and a Professional Communications course. Course outline for both courses are supplied in Appendix A.

It should be noted that since the whole Reactor Design course credits consist of 20.1% of the total of their year core-course credits, the student should spend 20.1% of their dedicated studying time on Reactor Design. Reactor Design expects at least 10 hours of self-study a week from the student.

3.4.2. The Course Content and Course Lectures

As the Reactor Design (RD) course is split into two semester courses, each semester is evaluated separately. The topics in RD have been divided in the following manner, outlined in Table 1.

Table 1: Topics in Reactor Design

Semester 1	Semester 2
<ul style="list-style-type: none"> • Ideal Reactors (2 weeks) • Reactor Staging (1 week) • Chemical Kinetics (1 week) • Rate Expressions from experimental data (2 weeks) • Series, Parallel and Complex reactions (4 weeks) • Residence Time Distributions (2 weeks) 	<ul style="list-style-type: none"> • Non-isothermal Reactor Design (4-5 weeks) • Multiple Steady States (1 week) • Heterogeneous Catalysis and Rate Expressions (2 weeks) • Transport Resistances in Heterogeneous Processes (2 weeks) • Non-catalytic Solid-fluid Reactions (2 weeks)

Each semester course is 12 weeks and is assigned three lectures and one tutorial session every week. There is also a fourth lecture a week which is used to teach students programming languages such as Matlab and Scilab to help them solve numerical problems.

An average of 2 weeks is spent on each topic. Depending on the lecturer, sometimes the Residence Time Distributions topic is shifted to the second semester. Although Residence Time Distributions is usually taught during the last two weeks of the first semester, the student sometimes needs those extra weeks to focus on studying on basics. Thus, instead of rushing this important section, there have been times where it has been shifted to the second semester which was what occurred in 2011.

In the present study Ideal Reactors, Chemical Kinetics, Residence Time Distributions and Non-Isothermal Energy Balances were selected as topics of focus as students have a history of struggling with these topics during the tests and examinations.

3.4.3. Course tutorials

Reactor Design tutorials typically run on Monday afternoons from 14h00 to 17h00. In each semester, there are at least ten tutorials. This means that there are on average 1-2 tutorials per topic. The tutorials are set by the lecturer and consist of several questions that are in line with course outcomes. The lecturer will have covered the material during the week and notes are provided. Students should also have the textbook which has the same material that the lecturer covers. Thus,

the student should be equipped with all the information needed to tackle the tutorial problems that the lecturer has set.

The student receives the tutorial three days in advance and must attempt the tutorial before attending the tutorial session. The tutorials need to be handed in on the Wednesday at 17h00. This means that the students are given sufficient time to finish the tutorials.

There is about 1 tutor for every 30 students. If students are struggling to answer the questions, then they may ask a tutor to help guide them towards the correct direction. The tutors are provided with tutorial solutions from the lecturer to make sure that the students are on the right track. As there are multiple ways of answering questions in Reactor Design, the tutorial solution from the lecturer is not the only possible solution.

3.4.4. Course outcomes

Students are expected to acquire and understand the knowledge being taught. Moreover, the student should be able to apply the knowledge and to solve problems in Reactor Design. The course outcomes are in line with ECSA and are all high level skills.

The knowledge areas are broken down for first semester as follows: Basic Science (20%), Engineering Sciences (35%), Design and Synthesis (35%) and Computer and IT (10%). For the second semester it is as follows: Basic Science (10%), Engineering Sciences (40%), Design and Synthesis (40%) and Computer and IT (10%).

3.4.5. Course assessment

At UCT, there are Duly Performed requirements where the student must fulfil certain requirements before being allowed to write the final examination. This is to ensure that the student does not pass solely on examination results but has worked consistently throughout the course and the semester. If a student does not meet the requirements, he or she will not be allowed to write the examination unless they have been successful in appealing for a concession for writing the examination.

Both semesters required satisfactory submission of 80% of the tutorials for each quarter. Satisfactory submission means that the student has attempted each question with a decent answer. There are only certain instances where satisfactory submission is not granted: when the student performed some sort of plagiarism, handed in late with no medical excuse or when the student has

not handed in the tutorial. Additionally, the student must also obtain an average of 40% for class tests 1 and class tests 2 together that accounted for 25% and 15% of the final mark respectively.

Finally, when student have fulfilled these requirements, they are allowed to write the course final examination. The written examination comprises 60% of the final course mark.

University of Cape Town

4. Development of animations

This section serves to give a brief insight as to how the animations were developed. It will also give some insight as to how the cognitive theories were incorporated into the design of the animations.

4.1. Concepts

As mentioned in Section 3.4.2, the students have a history of struggling with some Reactor design concepts, listed in Table 2. Each topic was investigated, and the topic of Non-isothermal Energy Balances was repeated.

Table 2: Investigation number and the correlating concepts

Topic	Investigation Number
Non-isothermal Energy Balance 2010	1
Basic Reactor Types	2
Reversible Reactions	3
Residence Time Distribution	4
Non-isothermal Energy Balance 2011	5

Although investigation 1 and investigation 5 are the same topic, the concepts are quite complicated. Thus, the concepts in investigation 1 focus on the kinetic rate constant, chemical equilibrium and jacketed reactors, whereas investigation 5 investigated students' understanding of the relationship between conversion and temperature, isorate lines and jacketed reactors. Investigation 2 focused on the basic reactors of a plug flow reactor (PFR), a continuous stirred tank reactor (CSTR) and the batch reactor. Investigation 3 focuses on reversible multiple parallel reaction and rate laws. Investigation 4 focused on Residence Time Distributions in different reactor types and step tracer pulses.

Investigation 2 is the simplest concept and with each succeeding investigation, the concepts became more complex and abstract. Investigation 1 and 5 are the most complex and abstract topics in this case study.

4.2. Programming language

The Python programming language was chosen as it is an object-orientated programme. It also has many set mathematical modules that are suitable for constructing the backbone of these simulated animations. These built-in libraries are relatively fast and are easy to use, thus allowing more time to focus on other aspects of the animation. Python also supports any extra modules that are fairly easy to import and implement.

Python version 2.5 was firstly used, and then was later upgraded to version 2.6. Version 2.6 had better numerical modules and could accommodate larger matrices. This was due to an upgraded built-in library of Numpy which allows for construction and fast manipulation of large matrices and a better graphics package.

VPython was the package of choice for the graphics of the animation as it has been created to be used in the educational environment. VPython has corresponding packages for the different versions of Python. VPython allows developers to render 3D graphics and display them in real-time, as well as providing control tools for manipulation of variables.

VPython has a built-in function so that developers do not need to know how graphics are rendered on-screen. As animations are pictures in sequence, with each update of the picture, it needs to clear the screen so that the new positions can be rendered onto the screen. However, this is not efficient as not all objects on screen necessarily change positions, thus leading to a waste of computing resources. VPython is able to reduce resources by only updating a portion of the screen that needs updating. The developer does not need to know how to clear and render objects as VPython already has built-in functions that do this for the developer.

PyInstaller was the Python library used to convert python programmes to become stand-alone executable programmes. A stand-alone programme is a programme that does not need installation of other programmes to run. Students can run the programme without installing Python. It was the only programme that enabled one to have all the Python libraries needed, compressed to one executable file, whereas Py2exe could not do this. But, with more complex systems and an upgraded version of Python, it seemed that PyInstaller was not so efficient at handling Vpython modules.

4.3. Graphics

4.3.1. Schematics

The physical components of a reactor are the vessel itself, all the material inside the reactor, and the inlet and outlet of the reactor. These physical components can be depicted ranging from symbolic to realistic.

In the present study, there was an option for a 3D display of graphical objects which could allow for objects to move in a 3D space. However, in an effort not to confuse the students, 3D objects were used but were placed on a 2D plane as shown as in Figure 2. This allows for clarity and for the objects not to overlap each other, for instance if one sphere is in front and the other is behind. By

having 3D objects, the lecturer hoped that the students would keep in mind that reactors and reactions happen in a 3D space.



Figure 2 : (a) is normal view and (b) is an isometric view to show the 2D plane in a 3D environment

As the familiarity with Python and its potential packages increased through the study, more options became available on the graphics and the format in which these were presented. The graphics then became more complex and efficient.

4.3.2. Reactors

Reactor Design focuses on four main types of reactors: a batch reactor, a plug flow reactor (PFR), a continuously stirred tank reactor (CSTR) and a packed bed reactor. The packed bed reactor involves heterogeneous reactions while the focus of the study is on homogenous reactions, thus only the first three reactors form the basis of these animations. Figure 3 shows typical symbolic forms of representing the reactors.

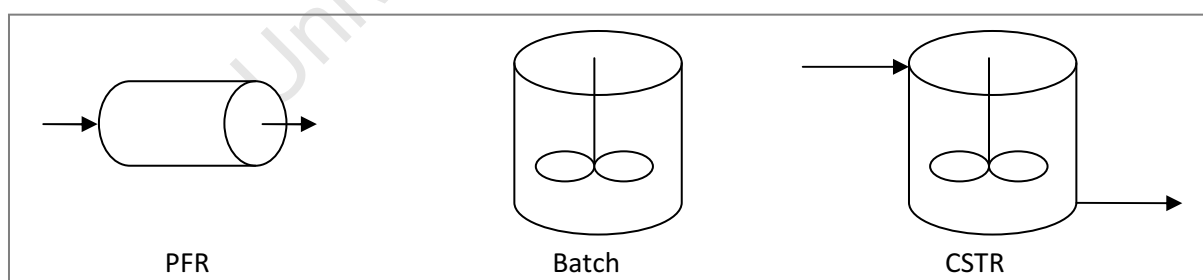


Figure 3: Typical symbols for reactors

In terms of graphical information, the reactor is a physical boundary that does not allow material to pass through. Furthermore, the space inside the reactor is the volume in which reactions are allowed to occur. In this study, the reactors themselves improved from line schematics to an opaque cylinder to a more realistic reactor as can be seen in Figure 4.

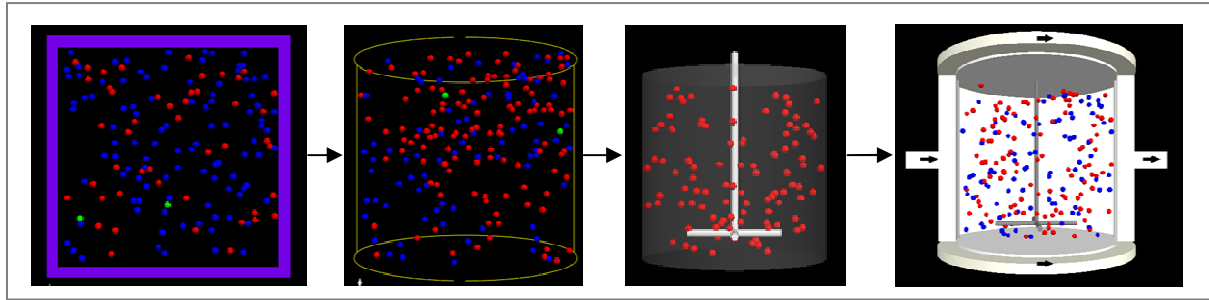


Figure 4: Example using batch reactors from various animations to show improvements over time

Agitators represent the mixing within the reactor. Agitators ensure that the contents of the batch reactor and CSTR are well mixed, and in an ideal case, the concentration in the batch and CSTR is the same throughout the tank. The agitators were of a 3D nature and thus one can see the turning of the agitators.

4.3.3. Material inside the reactor

Material inside the reactor involves some sort of reaction which consists of reactant, product and inerts. Three-dimensional spheres were used to represent reactant, product and tracer molecules.

Properties of the molecules were linked with several physical characteristics that can be displayed with a sphere. For instance, colours of the molecules were generally used to distinguish between reactants, products and tracers. In the Residence Time Distribution animations, a range of colours was used to depict how the molecules aged within the reactor (See screenshots of animation on CD).

Another property is the speed of the spheres, which can determine how long the molecules stay within a reactor. If the reactants stay in the reactor for longer periods of time, the higher the chance for reactants to convert into product, thus leading to an increased conversion. The speed of the sphere also depicts the flow rate in which it enters the reactor. In a steady state reactor, a high flow rate of material in will result in a high flow rate out. If the volume of the reactor is small and there is a high flow rate in, then the time spent in the reactor will be short, which could result in a low conversion of reactant.

The number of spheres depicts the number of moles of molecules in the reactor. The number of spheres in a volume depicts the concentration of molecules in the reactor. If the spheres, in a small volume of space, are grouped together, one can see that there is a higher concentration of material than a sparse group of spheres. Reaction rate is a function of concentration and temperature (unless

it is zeroth order, then concentration does not apply) and rate determines the conversion of molecules.

Because of limitations of physical computer memory to process information which is shown in Table 3, some spheres that exited the reactor have to be 'recycled' back into the system as a new molecule. This ensures that the computer memory is not overloaded by making a large number of particles. On an average computer in 2010 (see Table 3), the maximum number of molecules that could be displayed at any one time and ensuring the graphics are still continuous is 300 spheres.

Table 3: Computer specifications of an average computer in 2010

Computer hardware	Specifications
CPU	Intel (R) Core™ 2 Quad core Q6600 @2.40GHz
Read access Memory(RAM)	3.24 Gb
Graphics card	Nvidia 8500GT
Hard drive space	160 Gb

As only 300 spheres are allowed in the system, then eventually the material into the reactor will run out. Thus a recycling method is used to recycle the spheres exiting the reactor to be 'new' spheres. This method detects the position of the molecule on the screen. If the molecule is outside the reactor system then it will be invisible on the screen. All the spheres inside the reactor system can be seen, but the spheres outside the reactor system are the 'recycling programme'. When a new molecule needs to be released into the system, the programme will ask the 'recycling programme' for an available sphere which will then be released into the system. For more detail, please see Appendix C.2.

4.3.4. Graphs

Graphs represent information in a structured format. Keeping track of previous information that has been shown should improve the transient nature of animations. This is done by reducing the amount of cognitive resources needed to store previous information. There are two types of graphs used in the animation: line graphs and bar graphs. Both are made by using arrows from the VPython library. These two type graphs are illustrated in Figure 5.

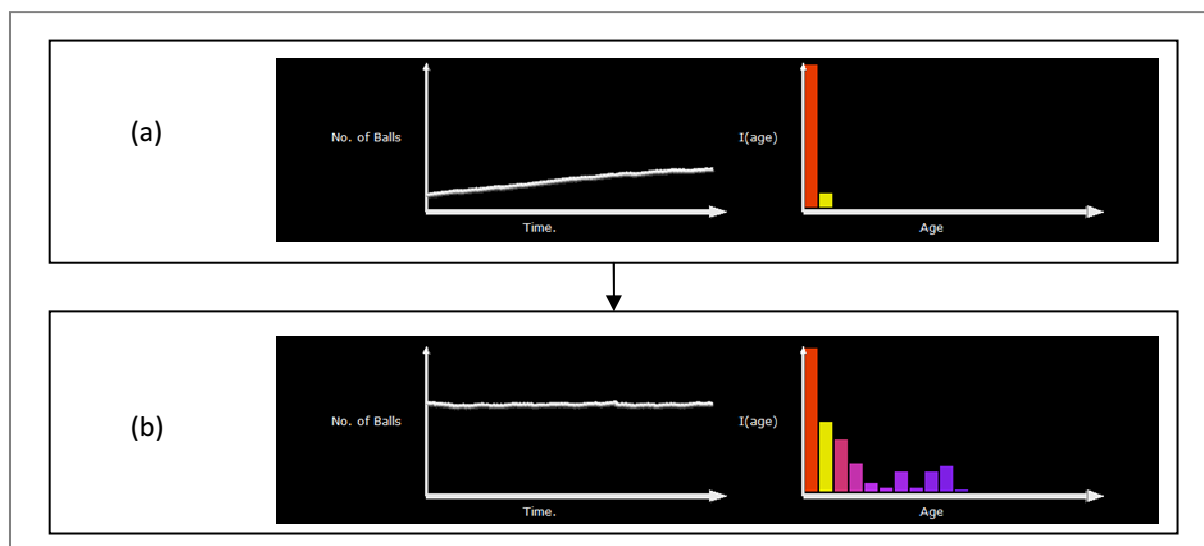


Figure 5: Example of graphs taken from investigation 4 (a) taken at time at 150 simulation seconds and (b) taken at 1500 simulations seconds

The lecturer needed animation graphs that displayed previous information for a set period of time; as this would decrease the transience in the animation. The line graph which can be seen on the left hand side in Figure 5, is an example of how to decrease working memory. As can be seen, the line segments update over time. The old information is deleted (on the extreme left hand side of the axis) and new information is stored and updated onto the right hand side of the axis (See Appendix C.4 for more information on how line graphs are constructed).

A second type of graph used was the bar graphs. These were mainly used for the Residence Time Distribution section (Investigation 4) as seen in Figure 5 on the right hand side. This allows the student to see a distribution of aging molecules. Bar graphs show the information in real-time. The difference between the line segment graph and the bar graph is that the bar graph does not need to shift old information as it does not store old information.

4.3.5. Background

The default setting of Python was a black background and the white font. A few students complained about not being able to see the molecules between the blue spheres for products and the black background. Thus, a light grey background was swapped for the black background in Investigation 3. This also proved to be a problem for the students as the boundary of the reactor was not as clear, thus, the old black background was implemented again in Investigations 4 and 5.

In the end, contrast is important to ensure visual acuity and the final format ended up with was a black background with light blue spheres instead of dark blue.

4.4. Mechanics

Each animation programme can take up to 1500 lines of code and has many functions within it to make it run efficiently. Figure 6 illustrates the simple structure of the programme to show how the animations were constructed (See Appendix C for a flowchart of the programme's basic structure).

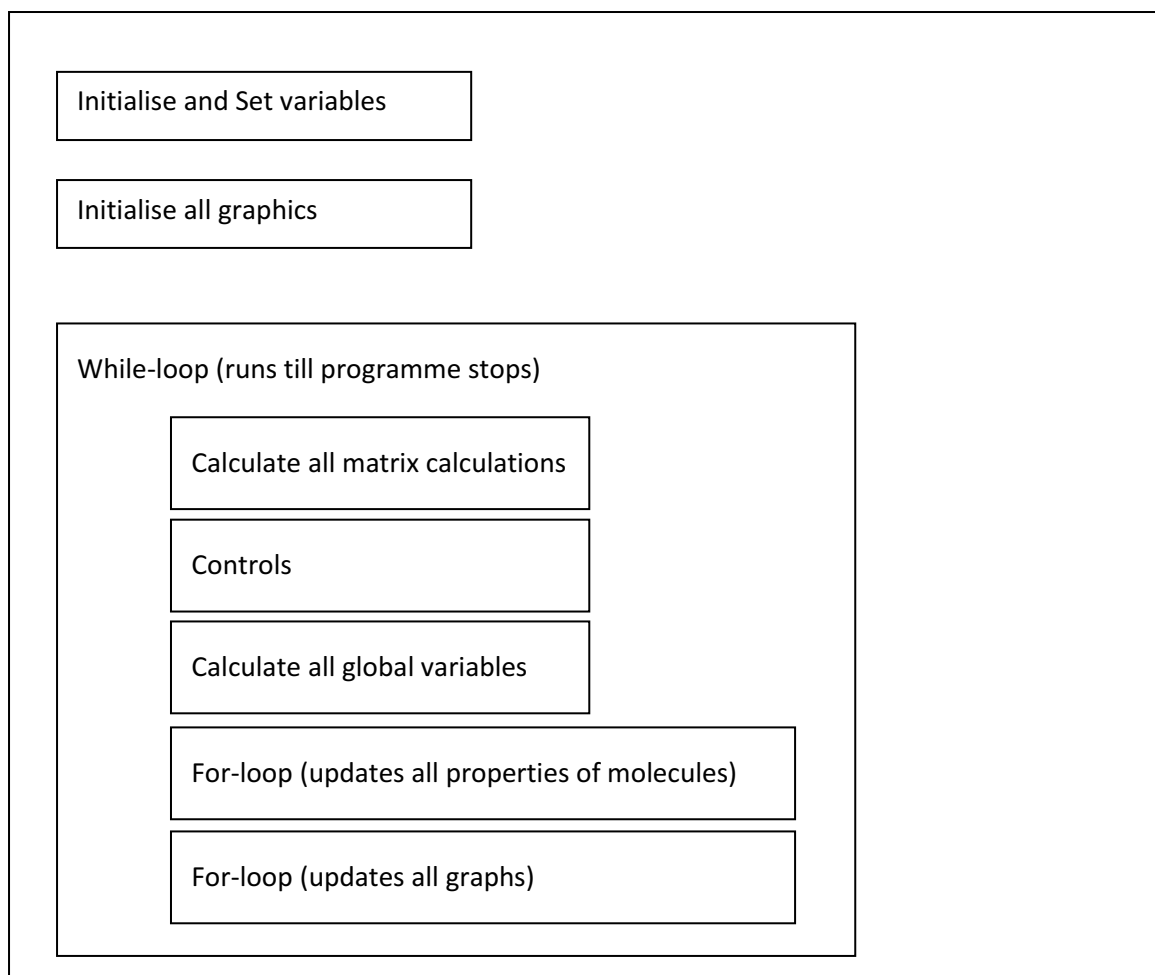


Figure 6: Basic algorithm showing the basic structure of the animation

At the beginning of the animation programme, all numbers and graphics are initialised. Some graphics do not really show changes in time such as graph axis and sometimes the reactor itself and are only initialised but no updates on those graphics are made. All the remaining graphics (that change in time) are dealt with in the while-loop.

One execution run of the while-loop is similar to one time step, with every loop it makes it will move onto the next time step. Any mouse interactions are detected in the control panel at the beginning of each time step and are calculated so that the influenced variables will be updated later on. For instance, if the water flow rate is decreased by clicking a slider via a mouse interaction (which can be

seen in Figure 7), this action is stored by the programme. The variable stored will be used in the calculations happening later in the while-loop.

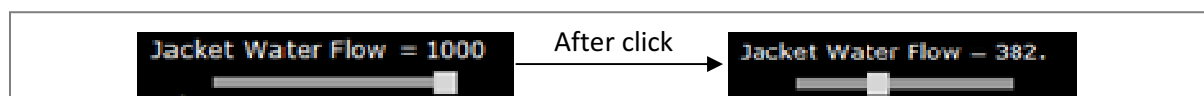


Figure 7: Example of how the mouse click influences the slider

Within each time step, a matrix calculation is used to determine where the sphere is and where the sphere should be next. This will determine the velocity of the sphere, and certain properties like its colour and whether it is invisible. Matrices were used as these would speed up the calculations (as the calculations were the same for each molecule).

For each individual update of the sphere, it is updated in the for-loop. The for-loop runs as many times as the number of molecules inside the reactor. However, the probability of the sphere changing colour is calculated with each for-loop, as the probability of each molecule changing from product to reactant is different with each time step.

By having too many for-loops in the while-loop would slow down the graphics, and thus all calculations were done in matrices before the for-loop as to optimise the programme allowing for more molecules in the reactor. The programme stops when the user quits the animation.

4.5. Controls

The graphics of the controls were already pre-programmed with VPython, making the controls easier to construct. The programme was able to detect where the mouse was on the control panel and was able to detect when the mouse was clicked, dragged and dropped. Interactivity, in this study, was used to manipulate variables and provide navigation control for the system - like pause and play. Although the ability of being able to use the controls was already built-in, the tools mentioned needed to be programmed for the functions that control the graphics. Having extra interactivity makes the programme complicated, and thus effective troubleshooting is important to make the overall programme run. An example of a control panel and its typical components is shown in Figure 8.

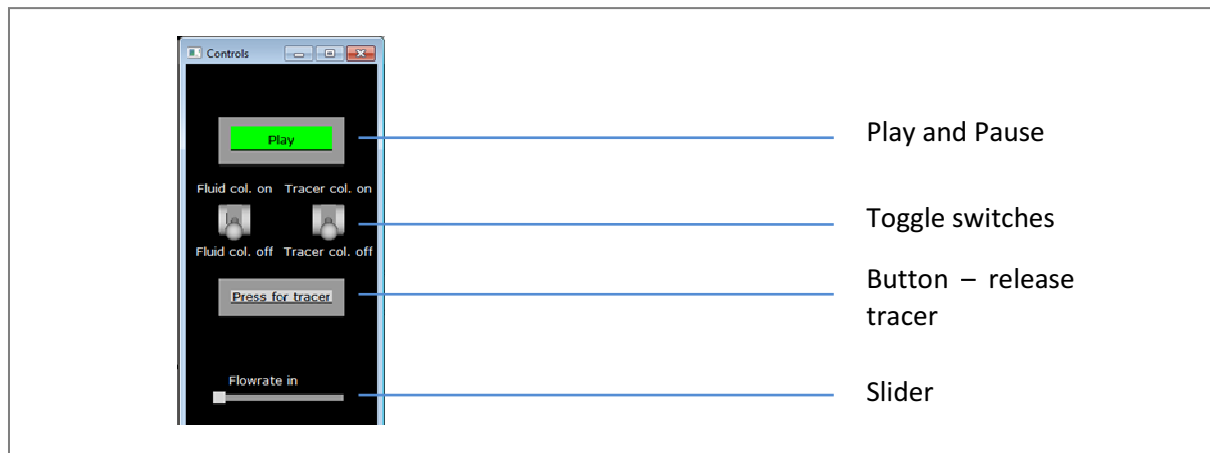


Figure 8: Labelled diagram of a control panel taken from Investigation 4

4.5.1. Sliders

Sliders are used as a means to control the variables within the reactor. However, variables are not necessarily independent of each other; this means when one variable is manipulated, it can affect other variables. There are two types of sliders that were implemented: reactor condition sliders and coupled sliders.

Reactor condition sliders control the variables within the reactor. The sliders are associated with a specific numerical value. The slider is a rectangle with an indicator to determine which value the slider is currently at. The left-hand side of the slider usually has a minimum but does not necessarily mean that it is zero. The right-hand side is usually a large number, and has a maximum value that is determined by the developer, which can be seen in Figure 9 .



Figure 9: Example of a flow rate slider taken from Investigation 5 and its (a) min. value and (b) max. value

Typically the slider values are linear, but they sometimes can be exponential. Typically sliders in this study were used to:

- Vary temperature and volume of the reactor
- Vary reaction rate constants and the chemical equilibrium constant
- Vary flow rate of reactant into the reactor

Coupled sliders are more difficult to control. It is important to ensure that the sliders that are dependent on each other do not update automatically as an infinite loop. Breaks have been added so that the slider will update once only.

4.5.2. Buttons and toggle switches

Buttons are used to activate some action; they may contain more than two options. On the other hand, the toggle button can only change between two options (Figure 8 shown earlier provides the visuals of a button and a toggle).

A typical button in the animation could do one of following functions:

- play and pause
- use as a navigation tool to navigate between different concepts
- use to release tracer into the system
- reset the animation
- use as a toggle between two options as well

4.5.3. Mouse interactions

Mouse interactions were detected by the VPython programme as part of the control module. However, there was a mouse interaction needed for the animation in investigation 5 which was not part of the VPython module. Thus, a custom control panel was created to accommodate the new mouse interactions, as can be seen in Figure 10. This control panel was created to ease the use of the animation and determine different initial states of the reactor. It ensured that the programme was able to detect the mouse position and determined where it was clicked on the control plane.

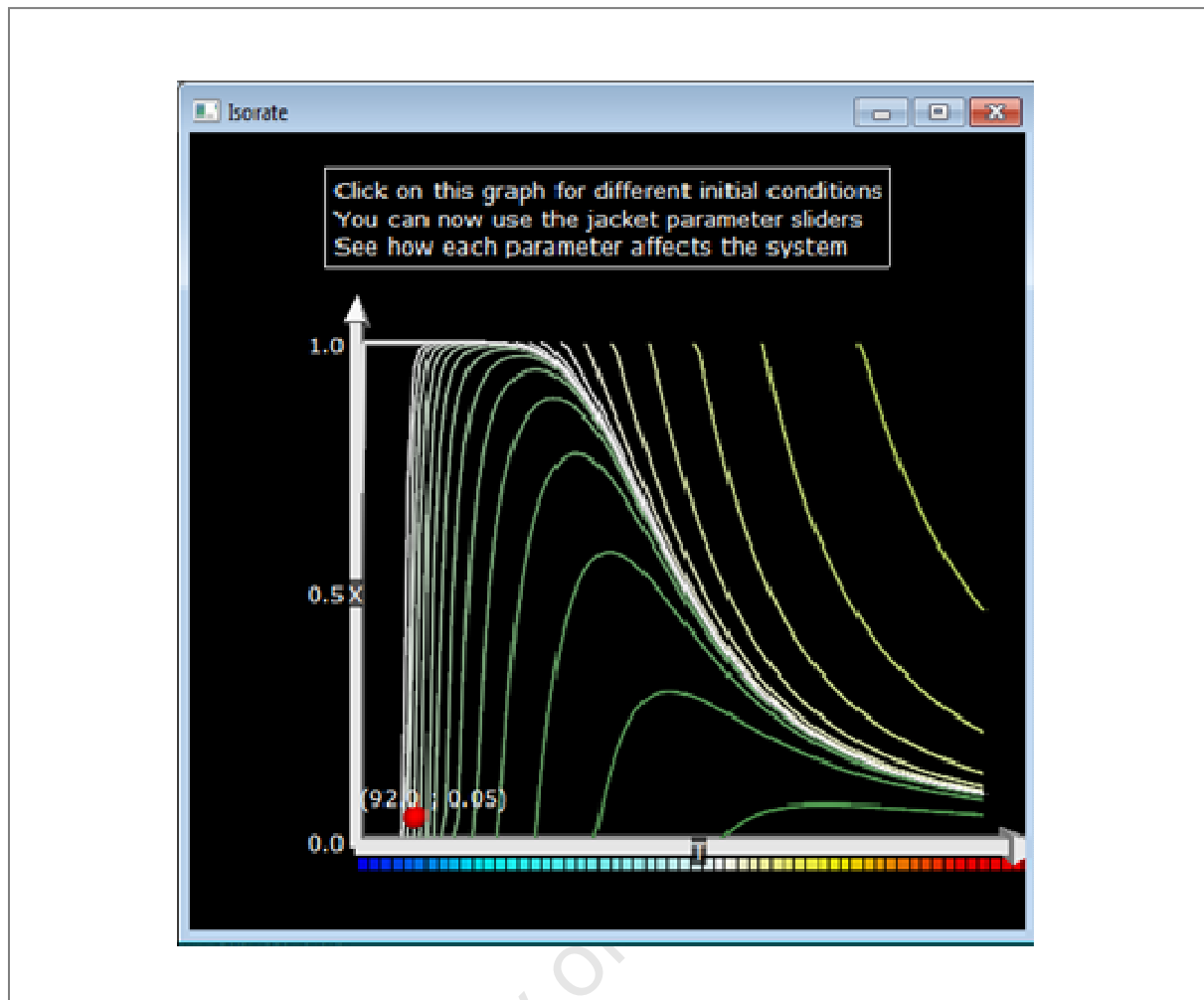


Figure 10: The custom control panel from Investigation 5 to accommodate new mouse interactions

5. Methods and Methodology

5.1. Methodology

Methodology is described by Crotty (1998, p3) as “the strategy, plan of action, process, or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes”.

Before the importance of methodology is discussed, it is imperative to distinguish between methodology and methods. Methods are the steps to investigate the research in order to get to the bottom of the questions around the research. In this instance, methods are the techniques to investigate phenomena.

Methodology, on the other hand, is used to explicitly choose from the choices of methods that are available, in order to answer the research question at hand (Case & Light, 2011).

Another main purpose for methodology is to justify the methods that have been used within the context of the study. Methodology validates the reliability of methods, as it justifies the assumptions. Although, methodology does not describe the methods, it describes the particular reasons for using that particular method compared to other available methods.

5.1.1. Case study

Case and Light (2011, p191) explain that a “case study as a methodology can be used as motivation for the validity of findings emerging either from an analysis of a single case or across multiple cases”. The present study is significantly different to the laboratory studies that involve experiments in an ideal situation; it is a real-life study within the 3rd year Reactor Design course in UCT. Thus, this research fits the description of a case study which is described by Robson (1993, p52) as “a strategy for doing research which involves empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence”.

Using the context of the study, the “contemporary phenomenon” is the use of animations in the classroom environment. The “empirical investigation [...] using multiple sources of evidence” is used to find the effectiveness of the animation on student performance. And finally, the “real life context” dictates the location and the available subjects in which the experiment occurs. It is also a “strategy” as there are other options that can be used to interpret data.

Case studies serve to connect the research question at hand to the way data was collected and the interpretation of the data collected. The case study's limitations may be that its boundaries must be within a certain context, but this also serves as one of its strengths (Case & Light, 2011). This means that this study can be used as a stepping stone for other researchers in the same context, as they can build on the knowledge that has been created.

Case studies allow for the researcher's own ideas and perspective about the project to be used as a resource in the study, instead of alienating the knowledge generated and discovered by the researcher during the course of conducting the case study (Robson, 1993). In literature, cognitive theories provided some guidance as to how animations should be made, but one could make an animation in any way one wanted for any topic (Weiss et al., 2002). The animations here are specific for Reactor Design and are customized for their use in instructional teaching.

Furthermore, this study is aimed towards assessing a phenomenon (in this case the effectiveness of an intervention) and generating new insights. This type of research can also be described as exploratory research. Exploratory research is consistent with case study as a methodology.

5.1.2. Experimental Design

As noted above, the study was located in the real world context of a third year Chemical Engineering course. Within this context, the decision was taken to frame the study in a quasi-experimental mode, dividing the class into 'control' and 'experimental' groups. A post-test was written by both groups to determine the differences between the two groups by using statistical analysis.

Quasi-experimental work differs from laboratory experiments as the quasi-experimental approach "attempts to liberalize the experiment to cope more realistically with conditions outside laboratory" (Robson, 1993, p47). Quasi-experimental design happens when random assignment was not used due to real-life conditions. In quasi-experimental design, one is unable to control all aspects of an experiment. Of course, even with the best experimental design, it is impossible to control all variables in a real-life world environment perfectly.

Pre-testing was considered in the process, but not used. Some studies which have investigated the impact of animations in education have used a pre-test method. This allows the researcher to find a direct check on the differences in the two groups such as finding out the students' differences in prior knowledge and their spatial abilities (see Canham and Hegarty, 2010; Cromley et al., 2010; de Koning et al., 2010a; Höffler et al., 2010; Kalyuga, 2008; Kombartzky et al., 2010; Lee and Shin, 2011;

Meyer et al., 2010; Münzer et al., 2009; Özmen et al., 2009; Rasch and Schnotz, 2009; Rieber et al., 1996; Scheiter et al., 2006; Scheiter et al., 2009; Schmidt-Weigand et al., 2010; Spanjers et al., 2011).

On the other hand, there are other studies that did not use a pre-test method (see de Koning et al., 2011; Korakakis et al., 2009; Kriz and Hegarty, 2007; Lowe, 2003, 2004; Pollock et al., 2002; Schnotz, 2003; Wouters et al., 2009). This is due to the fact that pre-testing could also offer unwanted disadvantages. Höffler et al. (2010) acknowledge the fact that pre-testing could be problematic' as the students are tested twice and could recall the previous test's information. By having the student being tested twice, it could sensitise those who are taking part by having them tested on the same thing twice (Robson, 1993). It also requires the same persons to participate in the experiment. As this is a voluntary experiment, students could choose not to participate during the course of the experiment. A measure of previous academic performance using second-year core-course marks was chosen instead of using a pre-test, as this prior knowledge is the prerequisite for the Reactor Design course.

There are many advantages to this simple post-test design, as both the groups can be tested at the same time so that the students do not have a chance to gain knowledge on a particular topic over time. It also ensures that the students' environmental factors are consistent at that time.

In experimental design, there are two types of validity that need to be considered to ensure the creditability of the experiment: internal validity and external validity (Robson, 1993). Internal validity is described by Robson (1993, p46) as "the extent to which the study has established that a factor or variable has actually caused the effect that has been found". On the other hand, external validity concerns the degree to which the results can be generalized. Different types of experimental design have different trade-offs between internal validity and external validity. In simpler terms, internal validity is about controlling within an experiment, and external validity is about the ability to generalise the experiment.

As this study is a case study, the purpose is to control the variables in this particular context but the results cannot be generalised to for all different contexts. In other words, for a case study, external validity is not as important as ensuring internal validity. By establishing internal validity, the observed variation can be assumed to have caused a certain outcome. This can be done by ruling out threats that compromise internal validity which will be discussed in section 5.2.8.

5.2. Research methods

5.2.1 Participants

The participants were third year Chemical Engineering students who were enrolled in either semester of the Reactor Design course. Participation was voluntary and anonymous. In each investigation, students were randomly assigned to one of two groups. The first group, designated a 'control' group, was taught in the traditional manner. The second group, the 'animation' group, was taught using the simulated animations. After the animations the students were required to complete comprehension tests, which sought to assess whether students could display an understanding of this new knowledge. Table 4 shows the number of students who participated in each investigation.

Table 4 : Table to display number of students in each group

Investigation	No. of students in Control lecture	No. of students in Experimental lecture	No. of students in who did not attend either lecture	Total Number of students
1	41 (41.4%)	33 (33.3%)	25 (25.3%)	99
2	72 (53.7%)	39 (29.1%)	23 (17.2%)	134
3	48 (35.8%)	59 (44.0%)	27 (20.2%)	134
4	40 (29.9%)	63 (47.0%)	31 (23.1%)	134
5	41(35.3%)	44 (38.0%)	31 (26.7)	116

Participants had no prior knowledge of the relevant concept unless the participant was repeating the course. An average of their second-year core-course marks was taken to give an overall overview of the student's second-year academic performance as a pre-test measure. An example of how the baseline was calculated can be seen in Appendix E, using Equation 1:

$$\text{Average 2nd year marks} = \frac{\sum(\text{course credit} \times \text{mark})}{\sum(\text{Number of times participating in course} \times \text{course credit})} \quad (\text{Eq. 1})$$

This average gave a good indication of the student's academic performance as the courses are mostly engineering subjects which are needed for the understanding of Reactor Design course. It also makes a distinction between students who have repeated other courses before as it accounts for students who failed and repeated courses.

The number of students repeating the Reactor Design course in each investigation is presented in Table 5. The percentage of repeating students who have attended the lecture shows that there is a low percentage of repeating students who attended the lectures. The students are repeating as they have failed the course and it was assumed that they have relatively low prior knowledge and their presence should not skew the findings.

Table 5: Table of number of repeating students

Investigation	Total no. of student present	No. of repeating students who attended either lecture (% of attendants)	Total no. of repeating students in class (% of total class)
1	74	5 (6.7%)	14 (14.1%)
2	111	10 (9.0%)	22 (16.9%)
3	104	11 (10.6%)	22 (16.9%)
4	114	7 (8.4%)	22 (19.3%)
5	116	7 (8.2%)	21 (18.1%)

5.2.2 Ethics

In order to conduct this study it was necessary to obtain approval from UCT both for access to students and for the ethics procedures (In Appendix D). These procedures were followed. At the beginning of 2010 and 2011, the course convenor introduced me to the class. I briefly described my project to the students and why I was doing this research. Students were invited to participate in the study. The sessions involved were optional extra activities that were, however, scheduled during course time. It was not compulsory that the students participate in these sessions.

I assured the students that their names would be kept anonymous. Should they feel they would like feedback on the test that they had written, they could put their student number on top of the script, and a photocopy of the test answers would be made and written feedback would be provided.

The students were randomly assigned to two different lecture groups. Both animations and lecture slides were placed onto the course website so that they could access the information after the experiment ended. The course convenor also allowed for a later demonstration of the animations to the control group, should the students of the control group wish to see the animation.

5.2.3 Procedures

There was limited time to present to both the animation and control groups within one class session. Each investigation was assigned either a lecture slot which consisted of one hour (Investigations 1, 3 and 5), or a tutorial slot, in which a little over two hours was allowed (Investigation 2 and 4). The time slots were split into thirds allowing for 15 minutes for the presentations that took place in a lecture time slot and about 40 minutes for the presentations that took place in a the tutorial time slot. The overall lecture times are given in Table 6.

Table 6: Summary of lecture duration

Investigation	Control Lecture Time (mins)	Animation Lecture time (mins)
1	14.1	18.5
2	36.0	42.3
3	16.2	21.6
4	40.2	49.0
5	14.6	17.0

Because the same lecturer needed to deliver both the control lecture and the experimental lecture, the following system was devised for both of these to take place within one session as displayed in Table 7.

Table 7: Timetable during the testing sessions for both groups

Split of available time	Control Venue	Animation Venue
First third of time slot	The lecturer was delivering the standard lecture	The students will have arrived in the second time slot
Second third of time slot	The student would be writing the post-test and completing the questionnaire after the lecture	The lecturer would be lecturing the animation lecture
Final third of time slot	The student could choose to stay behind to view animations after test	The student would be writing the post-test and completing the questionnaire after the lecture

In the first third of the time slot, the lecturer was lecturing the control group. At the same time, there were no students in the animation venue. After the lecturer had finished lecturing the students in the control venue, he moved to the animation venue. In the second third of the time slot, the control group were completing the test that the tutor in that venue had handed out to them. After the students had completed the test, they could fill out the questionnaire. In the other venue, the lecturer was lecturing the students in the animation group during this time. After the lecture, the lecturer left the animation group to go back to control group. The control group would have finished the test by now, and if they chose to stay, the lecturer would show the animations to the students who were keen. Alternatively, the animations and notes were uploaded onto the course website. In the final third time slot, the animation group would complete the same test but with a different questionnaire as shown in Appendix G.

After a student had completed the test, each student signed their name and student number on a register that differentiated them between the control and animation group. As the tests were anonymous and the marker did not know which student wrote which test and only knew which group they were in.

5.2.4 Materials and apparatus

As mentioned before, there were two versions of the learning material. The control group had a Powerpoint presentation with static pictures, words and equations. The animation group had an animation or a series of animations supplemented with the Powerpoint presentation to explain some equations. Both groups received verbal instruction, along with visual information, from the lecturer. Both these groups had the same information and followed the lesson structure. The material is in line with the course outcomes.

The animation that was developed in Python was controlled by the lecturer and cannot be controlled by the student. Thus, the lecturer determined the pace for learning. The lecturer could stop and play the animations and replay sections of the animation. The lecturer could also use the mouse as a visual cue to indicate on which part of the screen that the student should be focusing. The resolution of the animation is 768 by 1024 pixels. The whole screen is not necessarily used; this narrows the number of places where the student can focus on.

The control and animation groups were in different because they were exposed to different materials. Each classroom had a working projector and a blackboard. It was expected that about 80% of students would attend each session. Each venue can take between 50-60 students depending on the venue. The classrooms were within quick walking time between them so that the lecturer did not have to waste time walking between them.

A tutor was in each room to help invigilate and collect scripts while the lecturer was away from the venue. The tutor in the control venue also directed students to the animation venue if the student is late. Coming late for a fifteen minute lecture by even five minutes means that the student has missed a third of the lecture, thus making it not really worthwhile for the student to attend that lecture. Alternatively, students were in the wrong venue and thus did not attend the correct lecture. Thus the groups were modified from the original composition. Therefore, this group selection can certainly be described as 'quasi-random'.

5.2.5 Post-test

The comprehension tests were created by the lecturer. The comprehension tests were designed to test the student's understanding. As no standard tests exist in the area of Reactor Design, tests were based on the expected course outcomes. The Non-isothermal Energy Balance topic was repeated (investigation 5 had the same topic as investigation 1), but there were different questions to ensure clarity and shift the focus on the question as the animation had been modified. Investigation 1 was

more focused on the jacketed batch reactor, where investigation 5 was more focused on explaining the conversion versus temperature plane and the isorate lines.

The researcher used the lecturer's marking scheme to award marks. Full marks were awarded for the correct answer, and no marks were awarded if the answer was incorrect. However, partial marks were awarded if the student was on the right track but could not find the correct choice of words.

5.2.6 Questionnaire

The questionnaire, which focused on students' subjective experiences of the lecture or animation, was different in each topic and for each lecture group. However, the first two questions were the same the whole way through (See Appendix G). The two questions focused on the student's view on the lecture and whether they thought that they learnt from the lecture that they saw. It has a five point Likert scale rating from 1-5 with 1 indicating that they strongly disagreed with the question and 5 that they strongly agreed. These are the same ratings on the Vula system (a computer feedback system) in UCT which means the students should be familiar with the rating system.

For the control group session, there were 6 questions on each test. They stayed the same, with the exception of slight improvements to the wording over time. On the other hand, the experimental group had questions that were focused more on what type of aspects of the animation would they want to improve and whether they would use the animation as a study resource. The questionnaire acted as a feedback system so that the future animations could be improved.

5.2.7 Roles for the experiment

This section defines the roles of the individuals who were involved in the project. It will also show the variables in which the researcher could control and could not control and what defined those variables.

In my role as the researcher, I participated throughout the whole experiment. I had several roles before, during and after each investigation. The lecturer, also the course convenor, was involved before the investigation as well as during the experiments. The tutors only participated during the course of the investigation. The time frame of a typical investigation will be outlined here.

Before the actual investigation, I was given a date, time and duration of the lecture and a topic that was chosen by the lecturer. I then had to ensure that UCT had available rooms, and had to check whether these rooms were close in proximity. An outline of the topic was provided by the lecturer,

and I had to design a lesson, with the lecturer, that aligned with student learning outcomes. The lesson covered all key aspects of the topic. Furthermore, the lesson had to be able to be applicable to both the traditional lecture and the animation lecture. I designed and constructed the animations while checking if the lecturer approved of the development of the animation. I constructed the questionnaire while the lecturer developed the comprehension test. The lecturer would provide the marking scheme of the comprehension test.

A week before the testing, I would notify the students through the course website to inform them of dates, times and venue. The tutors would be briefed on how the session worked and written instructions were given additionally. The lecturer was also given the animation ahead of time so that he could familiarize himself with the animation. This was to ensure that everyone knew the procedure so that it would run as smoothly as possible.

During the experiment, I would guide the lecturer to the different lecture venues. As the lecturer started lecturing, the tutor would time the lecturer until he finished. The lecturer would lecture to the students and I would observe the lecturer and students while he spoke. I indicated to the lecturer when he was running out of time by putting up my hand to show how many minutes were left. The tutor would hand out all the test scripts and invigilate the test. After the scripts were collected, the tutor allowed the students to sign the register and complete the questionnaires.

After the investigation, I was the sole marker of the tests. I provided feedback to students who wanted their scripts back. I uploaded the test answers along with the animations and information on how to use the animations, on the course website.

5.2.8 Minimising the threats to internal validity

As noted earlier, the real world context for this study meant that it was not possible to conduct a fully controlled research design. There were aspects of how the course ran and the constraints which this offered, which could be considered as threats to the internal validity of the study. Where possible, it was attempted to reduce these as much as possible to ensure internal validity. The threats to internal validity categories were taken from Robson (1993, pp70-71). Only the ones that were applicable to my study are mentioned.

“History” described the events that have changed in the participant’s environment. This event could be a natural disaster or a political even such as an uprising. It is named “history” as the event could

be recorded in history as a major event. This threat was eliminated as the experiments were conducted right after each other and there were no major events.

The “testing” threat is due to repeated testing such as using pre-tests. As no pre-tests and re-testing of the same cohort were done, this threat was also eliminated. But on the hand, “instrumentation” was a threat, as the equipment and the classrooms were not the same every time. However, UCT’s standard of equipment is all the same and thus all the projectors were of the same brand and size. Furthermore, students sitting in the back of a large classroom as opposed to students sitting in front of a small classroom have different visual acuity. Although this threat is not eliminated, it has been reduced. The reason it could not be eliminated was due to the physical restraints of the availability of classrooms at UCT.

“Mortality” happens when students do not wish to participate in the study during the course of the study. This threat is inherent as experiment involving humans must be voluntary, and this means the sample size that was originally intended by researcher would be reduced. However, this was not a significant problem as the students who went to the lecture, stayed in the lecture.

The “maturation” threat was not so apparent in this study. There was not much opportunity for students to grow and develop over time as the students were tested immediately after the session and were given no prior information about the topic. This threat only really applied to the repeating students, but as noted above this was not considered a serious threat. As the control and experimental group were not selected in a particular manner or due to particular initial differences, the “selection” threat is eliminated. “Regression” is a similar issue in that it concerns whether the study chooses a particular group of students for their performance. Since this study initially randomised the groups, this threat is not inherent as the researcher did not treat the subjects differently if the subject had different scores.

However, the “diffusion of treatments” threat was not eliminated. “Diffusion” happens when the treatment has spread through the different groups. Some students have seen animation lectures on multiple occasions which means they could have become accustomed to learning from animation as they have some exposure to previous animations . For example, student A might have only seen the traditional lectures, whereas student B has seen only animations except for one investigation, where he or she was assigned to the control group. However, if the experiment was only allowed to be conducted with a fresh sample of students, the sample would be too small to have any statistical

impact. Thus, the same class of students was used over a number of investigations, with control and experimental groups randomly assigned to each investigation.

In summary, six of the eight threats to internal validity were eliminated and the other two were reduced due to the physical nature of this experiment. As with all natural experiments, it is impossible to control all variables, but internal validity has been reasonably well-established. This means that the methods that were chosen are valid for the case study.

5.3. Methods of data analysis

Statistical analyses on the quantitative data from the post-tests were conducted using a statistical programme called 'Stata'. The analysis was conducted to see whether there was a difference between the control and the animation group learning outcomes. The next part of the analysis focused on the quantitative data and qualitative data obtained from the questionnaires.

In the first part of the statistical analysis, the difference of initial academic performance of the two groups needed to be established; this is called the base-line score. This was being used in order to check if there was a bias between the control and experimental group. A t-test on each topic determined whether the groups in each topic are statistically the same or different. Further t-tests were conducted on the post-tests, to find differences in student performance in the different investigations.

To find the overall effect on whether the animations have worked across the different investigations, multivariate analysis (MVA) using ordinary least squares analysis (OLS) was used to conduct analysis over multiple variables (in this case the different investigations in the case study). OLS method is a linear regression model to compare the discrete independent variables (the individual investigations) to the continuous dependant variable (students' marks).

With regard to data on students' perceptions deriving from the questionnaires, the Likert scale data was analysed with basic descriptive statistics. The other questions were all open-ended questions and thus the data was analysed using qualitative content analysis. The questionnaire example can be found in Appendix G.

6. Results

The results gathered are based on the students' post-tests and written questionnaires. The quantitative data, as based on the post-test scores, will be discussed to answer the key question of whether the animations were effective in the Reactor Design context. The quantitative data that is drawn from the questionnaires will give an indication of the level of enjoyment and students' perspective on learning. The remaining qualitative data will provide more information about the student experience during the animation and the improvements students think should be made on the animations.

6.1. Quantitative data

6.1.1. T-tests

Baseline scores

This section compares the average students' academic performance in the second-year core-courses. Each student was correlated to the name written on the register to know to which group the student attended for each investigation. T-tests were conducted between the control group and the experimental group in each investigation to find whether there are differences between the students' average performances in these two groups. Table 8 shows the results of the t-tests to check whether there were academic differences in the composition of the two groups in each investigation.

Table 8: Baseline second-year marks

Investigation	Control group			Experimental group			Diff in mean (%)	Stats T-test
	Mean(%)	SE	#students	Mean(%)	SE	#students		
1	60.77	1.72	41	63.74	1.84	33	2.96	1.17
2	62.63	1.25	72	64.97	1.52	39	2.34	1.15
3	62.28	1.33	48	64.74	1.46	59	2.46	1.22
4	63.35	1.35	40	63.79	1.41	63	0.44	0.21
5	68.15	1.47	41	63.44	1.47	44	-4.71	-2.26*

*statistically significant at the 5% level

The difference in mean takes the control group's baseline marks subtracted from the animation's group mean baseline marks. This means when the value is positive, the animation group's baseline mark is higher than that of the control group's baseline mark.

When the t-test result sign is negative, it means that the academic results of the control group are higher than that of the animation group and vice versa. Standard error of the mean was used as opposed to standard deviation as standard deviation only indicates the spread of the distribution and is not normalised. The standard error not only maps the standard deviation on a normal distribution, but it is also able to account for the different sizes in samples. As larger samples have larger standard deviation, by using standard error of the mean will ensure that different sample sizes will not skew the error on the data. Using this method, one can statistically indicate, with a 95% confidence interval, that the score will fall in between two standard errors of the mean.

In the first four experiments, there was no statistical difference ($p > 0.10$) between the control and the animation group. This means that the students were randomised enough based on their performance. However, in the last investigation, the control group outperformed the animation group on second-year academic performance by 4.71 percentage points ($p < 0.05$).

Experiments

T-tests were also conducted to compare the differences between the control group and the animation group in the post-tests. These are the average results for the tests that the students wrote after viewing the lecture session, shown in Table 9.

Table 9: Results from investigation tests

Investigation	Control group			Experimental group			Diff in mean (%)	Stats T-test
	Mean(%)	SE	#student	Mean(%)	SE	#student		
1	54.96	2.99	41	52.73	3.33	33	-2.23	-0.50
2	39.08	1.63	72	37.71	1.91	39	-1.37	-0.52
3	51.00	2.07	48	43.15	2.11	59	-7.85	-2.62**
4	33.13	2.67	40	24.80	1.36	63	-8.32	-3.05**
5	36.34	2.35	41	37.73	2.20	44	1.38	+0.43

**statistically significant at the 1% level

Although in the first two investigations, the control group performed slightly better than the animation group, this result was statistically insignificant ($p > 0.10$). This meant there was not much difference in performance between the two groups. On the other hand, in investigation 3 and 4, the control groups outperformed the animation groups by 7.85 and 8.32 percentage points respectively ($p < 0.01$). It is interesting to note that in the final investigation, the animation group performed slightly better by a difference of 1.38 percentage points, but this difference was not statistically significant ($p > 0.10$).

There are a number of contextual factors that might have contributed towards the outperformance of the control group over the animation group, especially in investigations 3 and 4. The animation lectures in these instances were overcrowded. It was not foreseen to have so many students in one venue as it was not expected that many students would arrive late. Thus, the latecomers had to attend the animation lecture instead of attending the lecture that they were supposed to be in.

The lecturer determines the pace of the lecture, thus causing the varying times. Unfortunately, in investigation 3, the lecturer ran a little bit overtime in the control lecture making him late for the animation group. Furthermore, the lecturer also ran overtime again with the animation group, leaving the animation group under ten minutes to finish their tests.

Investigation 4 was problematic, as it was observed during the testing that the students were not focused on the lecture itself. Later, the researcher found out that the students had a deadline handing in a project for another course at the end of the day, that counted for 20% of their course mark. As the control group ended earlier, these students might have focused better during the course of the lecture. Unfortunately, for the animation group, they were focusing on handing in their projects and thus the students were rushing the writing of the test.

6.1.2. Regression

MVA (OLS) was used to analyse the data (as mentioned in 5.3) to determine whether the animations were effective in improving students' marks across the five investigations. The mean marks obtained by the students in the animation groups are compared to the mean mark of the control groups to determine the impact of the five investigations (where investigation 1 was used as the baseline investigation). This allows us to find the impact of the animation subjects collectively compared to the control subjects collectively as summarised in Table 10. The dependant marks are the marks of the students and the independent variables are whether they have been exposed to animations.

Table 10: Multivariate Analysis Ordinary Least Squares Method results

Number of Observations		480	
F(5,474)		32.03	
p		<0.001	
R ²		0.2525	
Independent variables	Difference in mean (%)	SE	Statistics (t)
Animation marks (AM)	-3.95	1.41	-2.81
Investigation 2 AM	-15.73	2.23	-6.92
Investigation 3 AM	-6.88	2.29	-3.00
Investigation 4 AM	-25.28	2.31	-10.90
Investigation 5 AM	-16.62	2.40	-6.90

All differences are statistically significant at the 1% level

The students who were exposed to the animation lectures did significantly worse by 3.95 percentage points ($p < 0.005$) than the students who were not exposed to the animation lectures. From the individual results, it can be seen that animation group results from investigations 2 to 5 all have significantly lower mean scores than animation group results from investigation 1 and are all statistically significant ($p < 0.01$). Investigations 4 and 5 had the lowest percentage points (25.28 and 16.62 percentage points respectively) compared to investigation 1. Furthermore, the R^2 is 0.2525, which suggests that some of the 25% variation in the student's marks is explained by the independent variables.

6.1.3. Students' perceptions

The first two questions in the questionnaires were constant throughout the entire study (See Appendix G). Both the animation group and the control group had these two questions. Students were asked to report their level of enjoyment of the lecture and their level of understanding gained from the lecture using the Likert-scale.

Students' reported level of enjoyment

The first question of the each student's questionnaire was to rate the level of enjoyment. The maximum rating is 5 for the questionnaire (see Appendix G). These results obtained from each investigation are summarised in Figure 11 to show the different levels of enjoyment between each group.

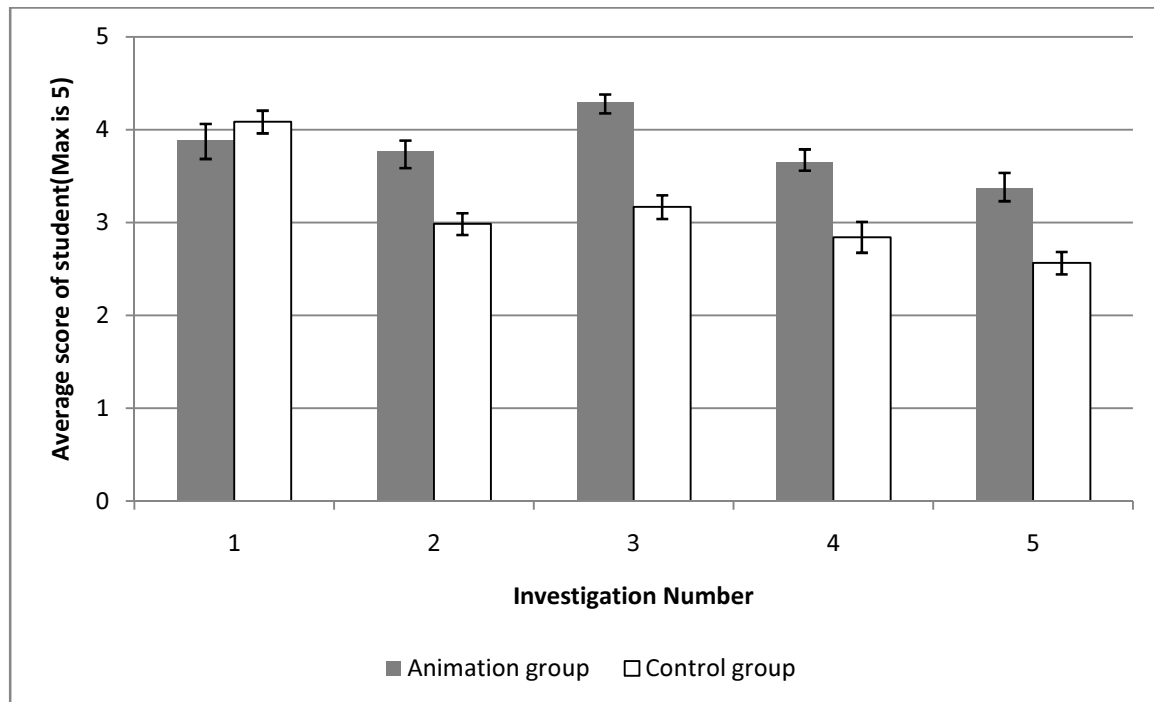


Figure 11: Reported enjoyment levels of students

In Figure 11, the error bars on the bar graphs is indicated with the standard error of the mean, as with each investigation, the sample sizes are different. As the groups were quasi-random, this meant different individual ratings for each group.

In the figure above, it can be seen that generally the animation group reported that they enjoyed the lecture more than the control group did. Animation groups had an average closer to four, where the control group had an average of three. With a rating of four, it meant that the students thought that the lecture was enjoyable and with ratings of three meant it was an average lecture.

Over the course of 2011, the data suggests that there is general decrease in students' reported enjoyment of the lectures. However, there is not strong enough evidence to support this as anything more than a suggestion as the Likert-scale is not a linear function and the scale is based on students' subjectivity.

Student's reported level of understanding

The second question in the questionnaire asks if the student thought he or she learnt the concepts in the lecture that they attended. Figure 12 shows the results obtained from this particular question.

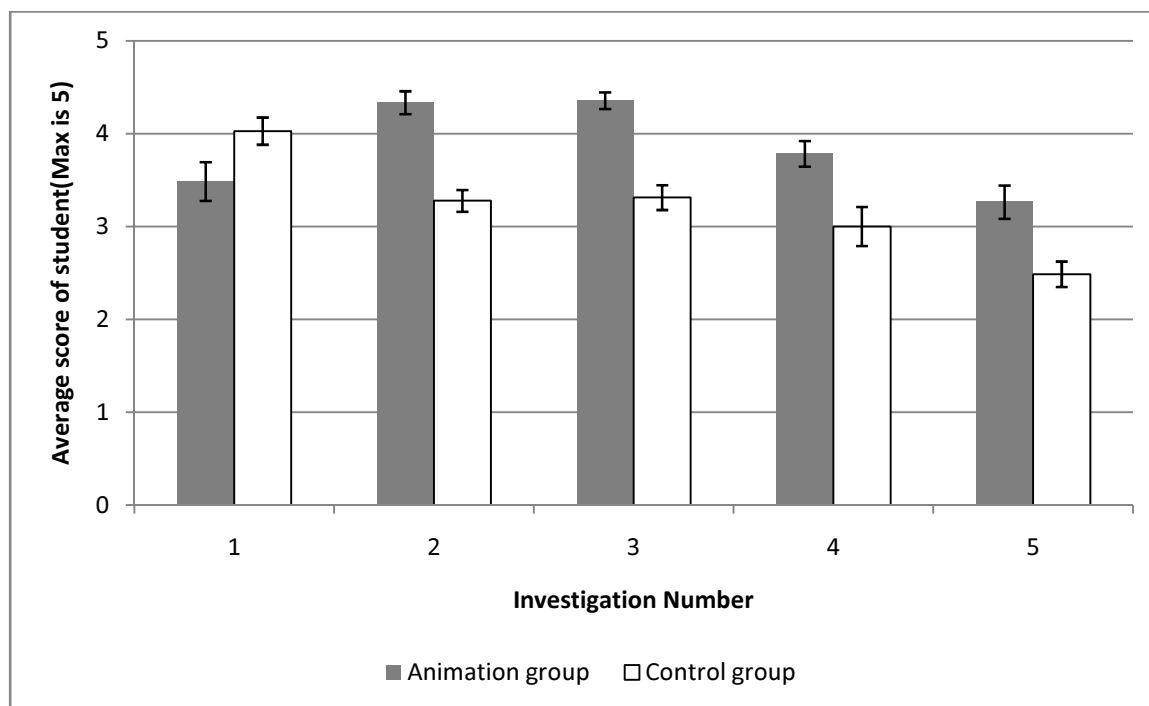


Figure 12: The students' perspective on whether they understood the concepts from the lecture

It is very interesting to note that the animation group generally thought they understood the concepts better than the control group for the last four investigations. On the other hand in investigation 1, which was conducted in 2010, the control group felt that they understood the concepts more than the animation group.

The graph possibly suggests that there is a downward trend in student's perception of understanding the concept. This may be due to the fact that investigation 1 and investigation 5 are the same concept but they are also the most difficult. Investigations 2 to 5 are in order of increasing complexity and difficulty.

6.2. Qualitative data

The analysis of the open-ended items in the questionnaires resulted in a small number of discrete themes. Some of the open-ended questions are not used here but were used then to suggest improvements for the forthcoming animations. For example, asking students which topic should the animation focus on next was just to give an indication of what the students would like as their next animation.

The overall assessments were taken from the animation group questionnaires as the interest lies in the students' perception of the animations. As mentioned before the questions were improved in

subsequent investigations so that there could be less ambiguity in the answers as some questions were initially too open-ended.

In contrast to the overall assessment, there were questions that targeted the students during a particular time (after an investigation) during the study. For instance, during the first few investigations we were interested in whether students would use the animation. But, by the time it is investigation 4, the students had been exposed to more investigations and are more likely to know how the investigation works and which of the ones they would choose.

6.2.1. Overall assessment

Aspects of the animation that student enjoyed

Students in the animations were asked which animations they enjoyed as summarised in Figure 13. Students were not limited to one answer and could list multiple aspects of the animations that they liked.

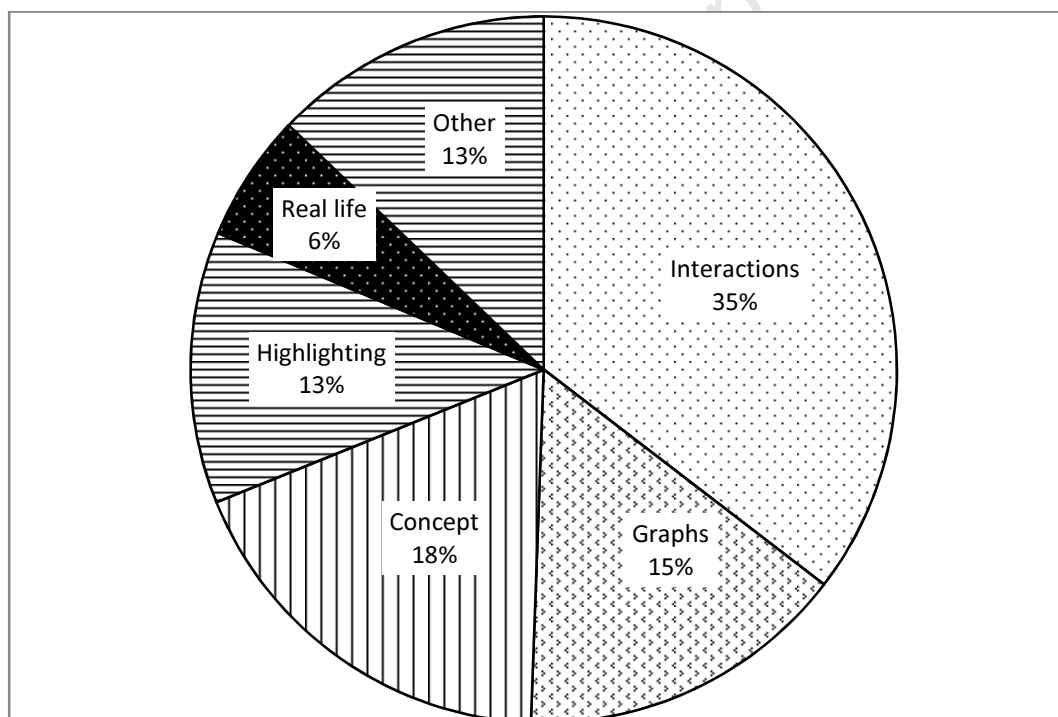


Figure 13: Students' responses on aspects of the animation they enjoyed

The different categories in Figure 13 will be explained from 'Interactions' and will follow a clockwise direction. 'Interactions' described anything about the controls of the system and how they could see the effect on the system to the overall movements in the animation. 'Graphs' described anything related to the graphs. Sometimes the student did not write a full answer and only put "graph" as an

answer. 'Concept' explained anything that includes that they liked the animation as they could understand the concept easily, or that the concept was well-structured. 'Highlighting' indicated anything that involves colour of the particles or anything that highlighted the system or concepts. 'Real-life' indicated that the students were interested in the real-life extensions of using the animation. This includes being able to see how it works inside the reactor and see how different reactors work. 'Other' indicated all the other responses, for example "everything", "it was interesting", "the concept was too simple", the animation was well-designed".

As can be seen, the 'Interactions' section of the pie chart is the largest section, and then followed by 'Concept', 'Graphs', 'Highlighting' and finally 'Real-life'. It is unusual for students to be able to see the inside of the reactor work in real-time, thus the dynamic system was new for students in a learning context. In investigation 4, the students also liked the fact that they could see the tracer input into the reactor.

On the other hand, the 'Concept' section was not as new as the dynamics of the system. The students were impressed with the structure of the content and how the animation portrays the content and 'how the variables tie in together'. Many students were also impressed with the graphs within the animation; this included many line graphs and bar graphs as part of the output section. One student said that "You can change the variables and observe the effects these changes directly". Another student mentioned that he or she liked "the fact that you can visualise the reaction. The graph that maps the reaction to concentration, equilibrium curves. You can play around with different conditions to see how different the outcomes will be". The student liked the fact that one could change the parameters and see the immediate effects.

'Highlighting' was most important in the investigation 4 and 5 animation sessions. This was due to the different colours that depicted aging in investigation 4's animation. In investigation 5's animation group, they enjoyed the visualisation aspect of the animation, and the colours that highlighted different aspects of the concepts. This included the flashing of the ball on the conversion temperature plane where it highlighted the overall forwards and reverse reaction rate.

Aspects on animation which students think can be improved

To give the developer some pointers for the next animation, the students pointed out some relevant improvements that could be made for future animations. The results are condensed into categories as displayed in Figure 14.

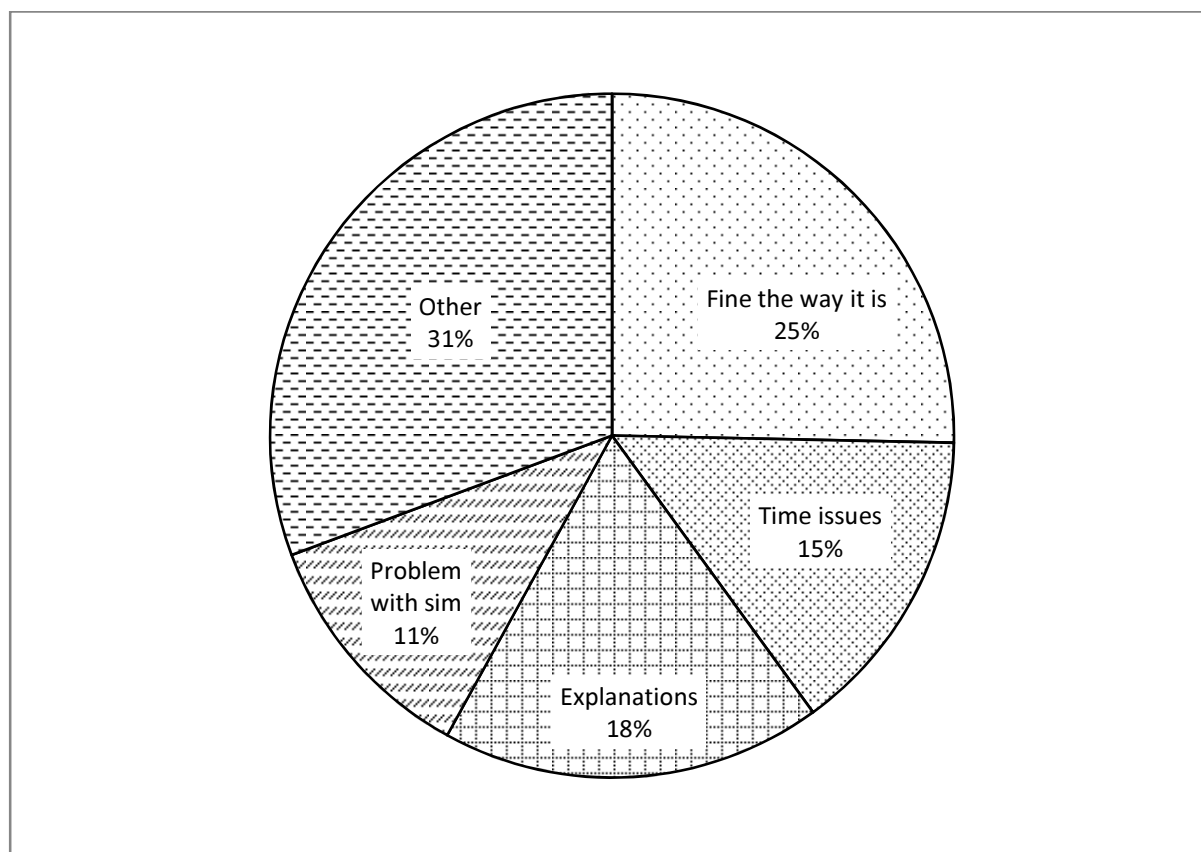


Figure 14: Students were asked which aspects of the animation could be improved

In Figure 14, 25% of the students said that the animation sessions were fine the way they were presented. 15% of the student felt there were problems with 'Time issue'. 'Time issues' could range from the length of the lecture to the lecture starting on time. 'Explanations' are that the explanation from the lecturer was not clear or they wanted the lecturer to break up the work into sections or they needed the lecturer to speak louder. Finally the 'Problem with the sim' included anything that the student had problem with during the animation session. During the one simulation, the lecturer pointed out the problems with the animation during the course of the experimental session to the students. He mentioned to the students that the curve in the animation would not be smooth due to the limited amount of balls within the system. He mentioned that more balls could be used. Another problem with the simulated animations was the black background, while sitting in a light room. One student also had a problem with the colour red and another student had a problem with the labels.

Other aspects that the student wanted to improve included "add[ing] sounds" to the animation; a student "want[ed] to see the code"; students wanted an air conditioned room as "it was a hot day"; the students wanted "hardcopy notes" or the "concept [was] too simple". However, these aspects could not be really classified as the students did not really answer the question that how the animation can be improved.

6.2.2. Staged assessment

Investigating initial student interest about using animations at home

Students from the animation groups were asked in investigations 1, 2 and 3 about whether they would use animations at home for studying. These were the initial investigations, and these questions were asked to see if the students were interested in animations after viewing them. There was a general positive response in students who were willing to use the animations at home for studying purposes.

88% of the students who responded said they would use animations as part of their future study. It seems that most students are willing to look at animations for studying purposes, as a potential extra source of information. The other 12% of the responses said that they would not use animations as part of their future study. As one student said that he or she “did not know how to use the animations”. The others did not give reasons.

Students’ preferred choice of lectures

Investigation 4 was the crucial time to ask questions that were related to students’ exposure to animations and which of the lecture type they preferred. Both the animation group and the control group had the same two questions. By this time in the first semester of 2011, there had been a total of three animation sessions. Investigation 4 ran a week before lectures ended. Theoretically, this meant that the student should have been preparing for examinations.

77% of the overall responses reported that they enjoyed animation lectures and the remainder said they preferred traditional lectures. Only one student in the class complained that he or she had not seen the animation lecture at all, but the student said that he or she would most likely enjoy the animation lecture if the chance were given to see it.

Students’ reported usage of animations

Figure 15 reports the results from investigation 4 on whether they used the animations uploaded onto the course website. ‘Yes’ or ‘No’ is the answer to whether they used the animations. The students that stated they were not aware that the animations were on the website were classified into the ‘Did not know’ category. The last category is the ‘Not yet’ category which refers to students who say they are intending to use the animations at a later stage.

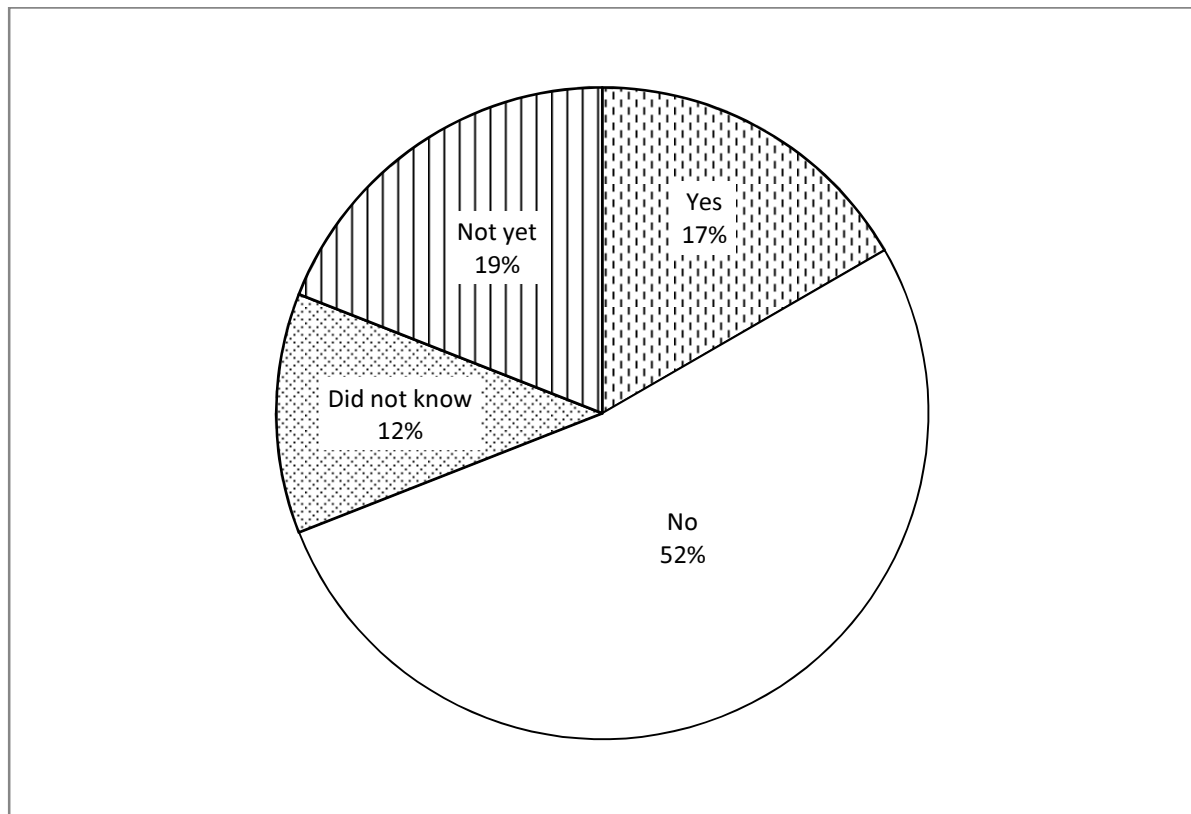


Figure 15: Students were asked whether they used animations on the website

The students who replied 'Yes' used the animation but they did not elaborate on whether they thought it was useful. Two students out of the 'Yes' sector said they did not know how to run the application, despite having careful instructions on how to run the animation (see Appendix H for example of instructions on how to use animations). On the other hand, 19% of the students were keen to use the animation in the "Not yet" category, who did not have enough time, but they were willing to use it for studying purposes. On the other hand, 12% of the students did not know that the animations were on the internet, even though there was notification to their email boxes about the animations being uploaded onto the course website.

7. Discussion

In the present study, five investigations were conducted to find the effectiveness of instructional animations in a Reactor Design course at the University of Cape Town. A summary will be drawn from the results from these investigations, which will answer the main research questions in this study.

7.1. Evidence for the effectiveness of animations

The key question of whether if this data supports the findings from literature regarding the comparison between animation and traditional ways of teaching, can be now answered. Using the MVA OLS results, the findings do not support a view that animations are effective ways of facilitating learning.

This study was a small scale case study of a maximum of 134 students at any one time. Some students have been sampled more than once in different investigations in this study. However, a large sample size of students was needed to answer the main research question and ensure that the investigation was still valid.

The results from the investigations in this study do support the mixed results on the effectiveness of animations that have been seen so far in literature (Tversky et al., 2000). Literature shows that there are cases where the animations were more effective for student learning than the control groups (see Tversky, 2002; Ginns, 2005; Höffler and Leutner, 2007 for meta-analyses). However, Tversky et al. (2002) suggests this result might have due to the fact that the animation portrayed more information than that of their traditional counterparts. On the other hand, there have been cases where the animation effectiveness was not proved useful at all, and have negative effects on student learning (Tversky et al., 2000; Chandler, 2009). If animations contained the same information as other traditional forms of teaching, then animation effectiveness should be the same as that of traditional forms, because the same information is portrayed but in a different manner.

Focusing on the individual investigations in this study using the t-tests results, there were three investigations that showed that animation effectiveness was no better than traditional forms of teaching. It has been ensured that the animations did not provide more information than that which was for the traditional methods of teaching, as it was specifically controlled for throughout the case study. If there was more information in the animation group such as the movement of particles,

then the lecturer would point out this information in the traditional lecture so that both groups had the same information as far as possible.

The other two remaining investigations indicated with statistical significance that the traditional forms of teaching were actually more effective than using animations. Literature suggests that the reason for this type of result might have been that the animations were distracting (Large, 1996; Tversky et al., 2002; Weiss et al., 2002) and the transient nature of animations might have affected the amount of cognitive resources available (Lowe, 2004).

Some studies (Lowe, 2004; Kriz and Hegarty, 2007) even argue that animations are too passive, and thus one cannot bring out the full potential in student learning. The animations used in this study served as a guided demonstration of how reactors work. Students are passive in the way they absorb information using animation (Large, 1996). To increase levels of engagement with the animations, interactivity with the animations was included.

“However, interactivity seems to be a value in its own right and produces positive results rather consistently” (Scheiter et al., 2006, p23). This refers to the self-paced animation studies, where students can re-inspect various aspects of the animation. Students could use these animations in their own time as there is interactivity involved in the animations provided, but it is difficult to isolate whether or not the knowledge gained was from the animations themselves, or from other activities such as learning from textbooks and notes.

However, the beauty of the combination of animation and interactivity is that when a variable is changed, the result can be seen on the screen immediately. This can be seen in the student’s positive feedback about how they see the immediate effects on the graphs, which is different to the graphical output from what is seen in the usual classroom exercise using MatLab and SciLab.

It should be noted that the students in the animation group in Investigation 3 did not have time to finish their tests due to the lecture starting five minutes late because to projector problems and the lecturer lecturing for too long. In Investigation 4, the slot was too close to examination time and the students might have been distracted by other responsibilities to which they had to attend such as handing in tutorials and projects. The transient nature of animations could have also contributed to the ineffectiveness of animation here, as the topics become increasingly more complicated with each animation and needed the students to use more cognitive resources than usual due to working memory restrictions (Lowe, 2004). Perhaps, the animation presentation speed was too fast (Chandler, 2009) for the students to comprehend as these were the more difficult topics in the first

semester of the Reactor Design course and there was too much information for them to process in the amount of time given.

On reflection it might be assumed that if the quasi-experiments were all running smoothly, the investigations that showed the animations had negative effects on student learning would have shown the same results as the investigation that showed no effect.

7.2. Students' perceived level of enjoyment

In most of the investigations, the general trend in Figure 11 suggests that the students who saw the animation lecture enjoyed it more than the students who saw the traditional lecture. The students reported their enjoyment rating of the lecture using a Likert-scale.

A possible explanation for this finding that the animation group in general enjoyed the lecture more than the control group is due to the "novelty effect" (Large, 1996, p10) or the "wow factor" (Chandler, 2009, p389). The novelty effect happens when new technology has been introduced into existing curricula. Animations were introduced as an attractive way to grab students' attention to make them more interested in the information presented (Large, 1996). In the study, the majority of the students' responses were that they were interested in the animation lecture more than a traditional lecture. This could be due to the novelty effect where the novelty of the animations lectures was attractive.

The third year class does use programming languages such as Matlab and SciLab which are part of the curriculum so that they have been able to programme numerical methods. This is different to the pre-programmed animations to teach conceptual information which were unlike the normal programming that was used in the course.

After a while, it can be anticipated that the novelty of incorporating animations will weaken over time and animations will have the same enjoyment level as that of a traditional lecture. The "novelty effect" will serve as a lure to attract students, but over time might not be enough to sustain students' motivation with over-usage of animations (Annetta et al., 2009). Therefore, careful consideration of animations should be advised as the ultimate goal is to find an effective way for students' to learn.

One of Mayer's (2002) methods to tackle the issue of the students' unfamiliarity with the animations (such as how to manage interactive dimensions) was to train the students to use the animations

beforehand. This could, however, also tone down the novelty effect as the students would have seen it before.

In the animation in this case study, there were interactive tools that allowed conditions to change within the reactor. This interactive capability was enjoyed by the students, as they have never seen an immediate change within a virtual reactor, which mimics a real-world counterpart. Due to the novelty effect, it is possible if students saw more of this type of interactivity, the positive effect could dissipate with time. But despite this, interactivity with reactors is a very powerful tool that instructors could use.

It was interesting to note that many students indicated they would use the animations at home. But many of them did not actually use it despite it being available to them during the semester. It could be that students did not think that the animation would be relevant for the examinations as the Reactor Design examinations mainly focus on calculations but not many marks are allocated to demonstrating conceptual understandings. Students' perceived level of understanding

This study found that the students felt that they understood the lecture content better when having the animation lecture compared to the traditional lecture (See Figure 12). Nevertheless, the students who attended the animations lectures did not perform any better in the post-tests than the students who attended the traditional lecture.

This finding might be related to the Hawthorne effect, where students in the experimental group think that if they are participating in the experiment, it will lead to change in behaviour such as thinking that animations will help them understand information more efficiently (McCarney et al., 2007). In this study, the empirical results contrasted to what the students reported about their perceived level of understanding. The students in the animation most likely thought that participating in the animation lecture was better than participating in a traditional lecture and thus changed their attitude towards participation in the different lecture venues.

The 2011 Reactor Design class reported that they preferred the animations lectures over the traditional lectures. A possible explanation for this thinking is that as they were participating in an experiment, they thought that the implementation of animations was more superior to traditional methods. It is similar to initial perceived idea of educators thinking animations are superior until they have seen the empirical evidence for the effectiveness of animations.

7.3. Limitations to the study and how it could be improved

The reader must be reminded that the study was set in a natural environment with limited resources as a quasi-experimental case study. The lecturer was trying to use an innovation (the animations) in his class to improve student learning. Indeed, there were limitations in this case study, for example, in having only one researcher who was also the marker of the post-tests, one lecturer, a small number of available appropriate classrooms, the allocation of different students to the groups and the time allowed for conducting these investigations. Furthermore, although it is not in the scope of the study, it was not possible to pinpoint the exact problems that students had when engaging with animations.

Many of these limitations may have contributed unwanted outcomes to the results of the study. However, this type of study in a naturalistic setting can never be more than a quasi-experimental one as it cannot ever be a 'true' experiment. Nonetheless, there are some directions to this study that could be improved should there be more resources and these are suggested below.

7.4.1 More research subjects

Different cohorts of subjects could affect the results. Investigation 1 was the 2010 group and Investigation 5 was the 2011 group for the Non-Isothermal Energy Balance topic. The average for investigation 1 was much higher than that of investigation 5. Possibly this means that the 2010 cohort had more students who understood the concepts better while being taught. If there were more students, a fresh sample of students could be used with every new investigation to ensure that students are complete novices to animations.

The scale of this study was quite small, as there were only 480 observations on about 30-70 students in each group. If there were a fresh group of students each time over more topics, then the statistics would be able to sample a better representation of a true population.

7.4.2 More time and resources

The different time variations of the durations between the animations and the control group are quite typical as seen in Scheiter et al. (2006), Kriz and Hegarty (2007) and Korakakis et al. (2009). It seems that the animations group did take a little longer than the control group. Re-inspection of the animation usually occurred, unlike static pictures where one can see the static picture or text permanently (Korakakis et al., 2009).

Students reported that the duration of the experiment was either too long (45 mins) or too short (15 mins). The long time slots were taken during tutorial time and the short slots were during the lecture times which were determined by the lecturer. Although 45 minutes is a normal lecture period, the researcher is not entirely sure why some student thought the lecture was too long. Perhaps, students are more used to having lectures in the morning and not in the afternoon. On the other hand, 15 minutes for a lecture that introduces a whole topic is quite short. The content of the lecture was compacted and could in fact cause an overwhelming effect for students in both groups.

Perhaps a week of animation lectures on one topic would have been more effective than showing one lecture for a topic. Should the researcher have more time to make more animations and test them over a longer period, this will allow one to see the effectiveness of animations over a long-term period.

As there was only one marker for all the investigations in this study, there could be some subjectivity in the marking of answers, despite the good intentions of the researcher to be fair. Another marker could have alleviated the marking subjectivity by checking if the two markers' grading was similar.

Furthermore, input from more lecturers who have taught the course in some manner could also allow for further proofreading of the questions so that the test questions are better clarified, understandable and have the correct standards.

7.4.3 A more direct measure on cognitive load

Although written comprehension tests provided quantitative feedback on student comprehension, it did not give accurate measures of how students engaged with the animation themselves. Perhaps this type of comprehension assessment was too open-ended and could not accurately measure the students' engagement with the animations. In contrast, traditional multiple choice problems could not pinpoint in which areas the students did not understand and there is also no requirement for students to explain their immediate thought processes when they make their final choice of answer (Kalyuga, 2008). If students explained their understanding step by step as in by studies done by De Koning and his fellow researchers (2010a, 2010b, 2011), then perhaps it might be possible to determine the gap where students are lacking understanding. This method could pinpoint some of the problems of how students engaged with animations.

To be able to see where the students are receiving information, some assessment of eye track movement could be used in addition to these comprehension tests. This will give an indication of

how the student selects information. Alternatively, if one has even more equipment and resources available for measuring cognitive load, one can use brain MRI imaging to find brain activity (Paas et al., 2003; Brunken et al., 2010).

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8. Conclusion and recommendations

Overall, the students that attended the animations lectures seemed to enjoy them much more than the students that attended the traditional lectures. However, this result could be explained by the novelty effect. In addition, the students in the animation group seemed to think that they understood more concepts than the students in the control group, which was contradicting the actual empirical test results. This could be a result of the Hawthorne effect.

In conclusion, animations were no more effective than traditional teaching for the Reactor Design classes in this case study. Further iterations of the animations with student feedback might deliver better results.

It is obvious that unpacking how student learn from animations is no simple matter (Chandler, 2009) and needs more insight into learning from animations than just analysing the effects seen from test outcomes. More research needs to investigate firstly where the students look on the screen, what information they process when they hear and see at the same time, and how they process each piece of information, to ensure that the student integrates the information correctly.

Although there has been a huge fascination with using animation in education in recent times, whether it is due to the novelty effects or not, the real potential benefits of using animation in education are not fully established. So much time and resources are invested in making animations to facilitate learning, but whether this time and resource is producing the desired effects, is also questionable. Animations could help bridge the gap for having students not needing to imagine the process, but at the same time, if students perceive the animation inaccurately, it is also not effective.

There are so many cognitive theories that one has to incorporate into making a 'successful' animation. However, even with the cognitive theories to guide researchers, it is difficult to make sure that animations were portraying concepts correctly. There were many limitations such as time, having experience and correct skills for making an animation. In the present study it is possible that more iterations on the same topics would probably enable better accommodating animations which include better graphics and more functions. But with the unlimited possibilities ways of designing animations, making good animations to ensure learning is very difficult indeed.

Animations definitely are compelling as if one has all the knowledge from programming, to graphics and the animation content itself, it feels like one can present information in any way one likes. But

for future researchers trying to make their own animations, it is difficult to make effective animations and use them to their full extent in an educational environment.

There still needs to be a lot of work on how student will learn effectively with animations. Here it is recommended that future researchers use animations to “hook” (Annetta et al., 2009, p80) their students onto a not too complicated topic that is typically mundane, but sustained interest cannot be guaranteed. By overusing animations, the researcher must be wary that there also may be unwanted results that come with this type of presentation of information. Perhaps, more iterations of using animations would make it be feasible for teaching Reactor Design as it could reduce the novelty effect and be able to pinpoint what problems that could arise.

Chandler (2004, p353) states in his commentary that “Instructors have frequently made the crucial mistake of allowing technology to generate the learning experience rather than using our growing knowledge of cognitive processes to guide us in how we can best utilize technology for instructional purposes”. Animations are certainly an attractive means of motivating students to learn, but their effectiveness will not necessarily be better than traditional methods of teaching. But one needs to see beyond the novelty effect (Chandler, 2009). With all methods of teaching, it is mindful teaching that counts and not the medium that one uses to teach.

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Appendices

Appendix A. Course Handout

Reactor Design I



Faculty of Engineering and the Built Environment

Department of Chemical Engineering

Course Outline, CHE3044F, 2011

Course Name:	CHE3044F Reactor Design I
SAQA Credits:	12
Pre-requisites:	CHE2031F, CEM2007F, DP in CHE2035S
Co-requisites:	None

Course convenor:	Klaus Möller
Email address:	klaus.moller@uct.ac.za
Office location:	Room 5.09, 5 th floor, Chemical Engineering Building
Consultation hours:	Anytime when possible, formally weekly at lunch time, best by arrangement via email
Course lecturers:	Maria Fernandez (maria.fernandez@uct.ac.za), Klaus Möller
Teaching assistants:	Alexander Opitz (senior TA, Alex.Opitz@uct.ac.za) Murray Fraser (Murray.Fraser@uct.ac.za) Mariam Royker (mariam.royker@uct.ac.za) Chimbganda Tapiwa (Chimbganda.Tapiwa@uct.ac.za) (Office hours & venues to be announced)

Lecture venue:	Unknown at time of preparation
Lecture days and time:	Monday-Thursday, 10h00-11h00
Tutorial venues	Unknown at time of preparation
Tutorial day and time	Monday 14h00-17h00

Course objectives

To understand Isothermal Homogeneous Reactor Design :

Concepts of mole (mass) balances over reactors with ideal flow patterns (plug flow, mixed flow, batch, semi-batch, membrane, bio-chemical, recycle reactors). Combining and sequencing reactor types. Reaction rate laws, reaction kinetics and elementary reactions. Designing reactors with ideal flow patterns. Interpreting and analysing experimental reaction data. Residence time distributions. Isothermal reactor

design with non-ideal flow patterns.

Learning outcomes

Students successfully completing this course will have the following:	At level	Exit level	ELO 1	ELO 2	ELO 3	ELO 4	ELO 5	ELO 6	ELO 7	ELO 8	ELO 9	ELO 10
A. Knowledge (Information plus Understanding)												
1. Chemical reaction kinetics and rate processes			8									
2. Understand development of reactor mole balance			8									
3. The role of ideal mixing patterns in chemical reactors (batch, PFR, CSTR)	Y			7								
4. Importance of pressure drop in plug flow reactors	Y			7								
5. Residence time distribution theory	Y		8									
B. Skills (Application of Knowledge)												
1. be able to describe chemical reaction processes in terms of ideal and practical models	Y			8								
2. have an understanding of chemical reaction kinetics and of rate processes in general					8							
2. the concept and application of residence time distributions in chemical processes					8							
3. be able to apply computer based problem solution techniques to chemical reaction problems						8						
4. be able to interpret experimental rate data, directly and with the aid of reactor models	Y				8							
5. be able to select chemical reactors for given duties					8							
C. Values and Attitudes												
1. be able to work and learn independently											8	
2. be able to study using computer based methods of self evaluation							8					
3. be able to source and select information										8		
4. appreciate the necessity for self discipline, time management and professional conduct.												8

Detailed course content

Topics	Knowledge Areas					
	Mathematics	Basic Sciences	Engineering Sciences	Design and Synthesis	Computing and IT	Complementary Studies

Appendices

i. Mole balances: • Develop Reactor Design Equations for ideal mixing patterns		5%	10%	5%		
ii. Reactor networks: • PFR/CSTR sequencing • PFR design, pressure drop and recycle			10%	10%		
iii. Reaction kinetics • Stoichiometry, Basic kinetics • Series and parallel reactions • Complex reactions • Collection and analysis of rate data		15%			5%	
iv. Mixing in chemical reactors • Residence time distribution concepts • RTD of ideal reactors • RTD of non-ideal reactors • Segregation models • Micro-mixing			10%	10%	5%	
v. Biochemical Reaction Engineering • Biochemistry • Bioreaction fundamentals • Introduction to Bioreactors			5%	10%		
Total		20%	35%	35%	10%	

Learning environment

Notionally: 36 lecture slots and 12 tutorial (48 lecture slots have been timetabled)

The course will be delivered largely through lectures, tutorials, computer sessions

Suggested time

Learning Activity	Time (hours)
Lectures	27
Tutorials	24
Unsupervised study and preparatory work	39
Exam and test preparation and writing	30
Total learning time	120

General assessment strategy and DP requirements

NOTE : This assessment strategy and DP requirements supersede those published in the Faculty Handbook

Assessment Task	%	The following DP rules apply:
Spot tests (5 x 2%)	10	40% or more for spot tests 40% or more for tutorial tests
Tutorial Tests (0.5 h)	10	
Class test 1 (3 h)	20	

Appendices

Computer exam (1.5 h)	5	40% or more for class test
Written examination (3 h)	55	
Total	100	

Class test and computer exam dates will be announced in due course.

Most likely dates :

Class test 1 : first week after the mid semester break

Computer exam : last week of the first semester **Information specific to ELOs**

Outcome A3: The role of ideal mixing patterns in chemical reactors (batch, PFR, CSTR)

Outcome A4: Importance of pressure drop in plug flow reactors

Outcome A5: Residence time distribution theory

Outcome B1: be able to describe chemical reaction processes in terms of ideal and practical models

Outcome B4: be able to interpret experimental rate data, directly and with the aid of reactor models

Where and how is this learning outcome assessed?

In the tests and in the final examination.

What constitutes satisfactory performance?

Passing the tests and examination.

What strategy is to be followed should this learning outcome not be satisfactorily attained?

The course will need to be repeated.

Prescribed Books/Reading Materials/Notes

Prescribed book

(1) H. Scott Fogler, Elements of Chemical Reaction Engineering – 4th Ed.

Other interesting reading and source of valuable insight

(1) LD Schmidt, The Engineering of Chemical reactions, 2nd ed., Oxford Univ Press, 2005.

(2) O Levenspiel, Chemical Reaction Engineering, 3rd ed., Wiley, 1999.

Reactor Design II



Faculty of Engineering and the Built Environment

Department of Chemical Engineering

Course Outline, CHE3054S, 2010

Course Name:	CHE3054S Reactor Design II
SAQA Credits:	16
Pre-requisites:	CHE2036S, DP in CHE3044F, CHE3046F and CHE3063F
Co-requisites:	None

Course convenor:	Dr Randhir Rawatlal
Email address:	Randhir.Rawatlal@uct.ac.za
Office location:	Room 4.12, Chemical Engineering Building
Consultation hours:	Mon-Thurs 09h00-10h00 (appointments can be made at other times)
Course lecturer:	Dr Randhir Rawatlal, A/Prof Klaus Möller (Klaus.moller@uct.ac.za)
Teaching assistants:	Alex Opitz (Senior TA, Alex.Opitz@uct.ac.za) Bryan Maas (Bryan.Maas@uct.ac.za) Karen Ma (Karen.Ma@uct.ac.za) Nabeel Hussain (Nabeel.Hussain@uct.ac.za) (Office hours & venues to be announced)

Lecture venue:	EM5 (Electro-Mechanical Lecture Hall 5)
Lecture days and time:	Monday-Thursday, 10h00-11h00
Tutorial venues	DO2, Menzies Bldg
Tutorial day and time	Monday 14h00-17h00

Course objectives

To understand the role of temperature control on reactor operation and dynamics, and to design such systems for heterogeneously catalyzed cases under conditions of both well-defined and imperfectly mixed flow regimes based on a rigorously fundamental reaction kinetic framework.

COURSE CONTENT

- 3054.5. The energy balance in reactor design
 - 3054.51 Energy balance in CSTR
 - 3054.511 Adiabatic

Appendices

- 3054.512 Isothermal operation
 - 3054.52 Energy balance in PFR
 - 3054.521 Adiabatic
 - 3054.522 Isothermal operation
 - 3054.53 Maximum rate path in batch reactors
- 3054.6 Start-up/shutdown of reactors
- 3054.7 Heterogeneously catalysed reactions
 - 3054.732 Langmuir Hinshelwood kinetics
- 3054.8 Solid-fluid reactions
- 3054.9 Residence time distribution theory

Learning outcomes

Students successfully completing this course will have the following:	At level	Exit level	ELO 1	ELO 2	ELO 3	ELO 4	ELO 5	ELO 6	ELO 7	ELO 8	ELO 9	ELO 10
A. Knowledge (Information plus Understanding)												
6. The fundamental energy balance in chemical reactors				8								
7. Dynamics analysis of energy conservation				8								
8. Unsteady state operation in Batch, Semi-batch and CSTRs					8							
9. Langmuir Hinschelwood kinetics				8								
10. Reaction-diffusion and activity in heterogeneous catalysis	Y				8							
11. Shrinking particle models	Y				8							
12. Residence time distribution theory	Y				8							
B. Skills (Application of Knowledge)												
6. be able to develop and solve the energy balance for ideal mixing patterns in terms of reactor temperature	Y				8							
7. be able to analyse the dynamics of heat transfer in a reactor system						8						
8. be able to develop start-up and shut-down procedures based on an unsteady state design model	Y				8							
9. be able to develop possible reaction rate expressions from a set of reaction mechanisms and use them to determine which mechanism controls the rate	Y				8							
10. be able to design a catalysed reactor system where mass transfer and deactivation plays a significant role	Y				8							
11. be able to design a reactor system in which solid-fluid reactions occur	Y				8							
12. be able to apply concepts of segregation and compartmentalization to design reactor systems for both well-defined and imperfectly mixed fluids	Y				8							
C. Values and Attitudes												
5. be able to work and learn independently											8	
6. be able to study using computer based methods of self							8					

Appendices

evaluation														
7. be able to source and select information													8	
8. appreciate the necessity for self discipline, time management and professional conduct.														8

Detailed course content

Topics	Knowledge Areas					
	Mathematics	Basic Sciences	Engineering Sciences	Design and Synthesis	Computing and IT	Complementary Studies
vi. Energy balance: <ul style="list-style-type: none"> Develop and simulate adiabatic Reactor Design Equations for ideal mixing patterns Develop and simulate isothermal Reactor Design Equations for ideal mixing patterns 			5%	10%	5%	
vii. Dynamics, unsteady operation: <ul style="list-style-type: none"> Thermal dynamics Unsteady state operation of batch, semi-batch, CSTR; startup and shutdown 			5%	10%	5%	
viii. Heterogeneous catalysis <ul style="list-style-type: none"> Langmuir Hinselwood kinetics, reaction mechanisms BET theory Catalyst activity Reaction Diffusion; effectiveness factor 		10%	5%	5%		
ix. Solid-fluid reactions <ul style="list-style-type: none"> Shrinking particle models Shrinking core models 			10%	5%		
x. Mixing in chemical reactors <ul style="list-style-type: none"> Residence time distribution concepts RTD of ideal reactors RTD of non-ideal reactors Segregation models Micro-mixing 			15%	10%		
Total		10%	40%	40%	10%	

Learning environment

Notionally: 48 lecture slots and 12 tutorial slots (actually 36 lecture slots and 12 tutorial slots)

The course will be delivered largely through lectures and tutorials. Two class tests scheduled.

Suggested time allocation

Appendices

Learning Activity	Time (hours)
Lectures	36
Tutorials	36
Unsupervised study and preparatory work	50
Exam/test preparation and writing	38
Total learning time	160

General assessment strategy

Assessment Task	%	The following DP rules apply:
Class tests (3 hours – 25%, 2 hours – 15%)	40	Course mark (calculated from the two tests) of at least 40%, AND Satisfactory submission of 4 of tutorials 1, 2, 3, 4, 5 AND 3 of tutorials 6, 7, 8, 9
Written examination	60	
Total	100	

Information specific to ELOs

<p>Outcome A5: Reaction-diffusion and activity in heterogeneous catalysis</p> <p>Outcome A6: Solid-fluid reactions</p> <p>Outcome A7: Residence time distribution theory</p> <p>Outcome B1: be able to develop and solve the energy balance for ideal mixing patterns in terms of reactor temperature</p> <p>Outcome B3: be able to develop start-up and shut-down procedures based on an unsteady state design model</p> <p>Outcome B4: be able to develop possible reaction rate expressions from a set of reaction mechanisms and use them to determine which mechanism controls the rate</p> <p>Outcome B5: be able to design a catalysed reactor system where mass transfer and deactivation plays a significant role</p> <p>Outcome B6: be able to design a reactor system in which solid-fluid reactions occur</p> <p>Outcome B7: be able to apply concepts of segregation and compartmentalization to design reactor systems for both well-defined and imperfectly mixed fluids</p>
<p><i>Where and how is this learning outcome assessed?</i></p> <p>In the tests, the design project, and in the final examination.</p>
<p><i>What constitutes satisfactory performance?</i></p> <p>Passing the tests and examination and producing a design that shows respect for and understanding of each of these issues.</p>
<p><i>What strategy is to be followed should this learning outcome not be satisfactorily attained?</i></p> <p>The course will need to be repeated.</p>

Prescribed Books/Reading Materials/Notes

<p>Prescribed book</p> <p>(1) H. Scott Fogler, Elements of Chemical Reaction Engineering – 4th Ed.</p>
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Appendix B. Animations

The animation in investigation 1 is given as a stand-alone executable file. All other animations are given as screenshots in the Powerpoint presentation. Both are located on the CD provided.

Appendix C. Algorithm of Animation Programme from Investigation 5

The algorithms on how the different components will be explained here as to explain how the programme in Investigation 5 was coded. This will provide an example for all the other animations as majority of the functions were utilised in this animation. In addition, this animation also used many Reactor Design equations such as the isorate lines, mass balance on the reactor, the energy balance on the reactor and equations involving the jacketed reactor. The reactor starts in unsteady state. A flowchart is shown in Figure 16 to how the programme works.

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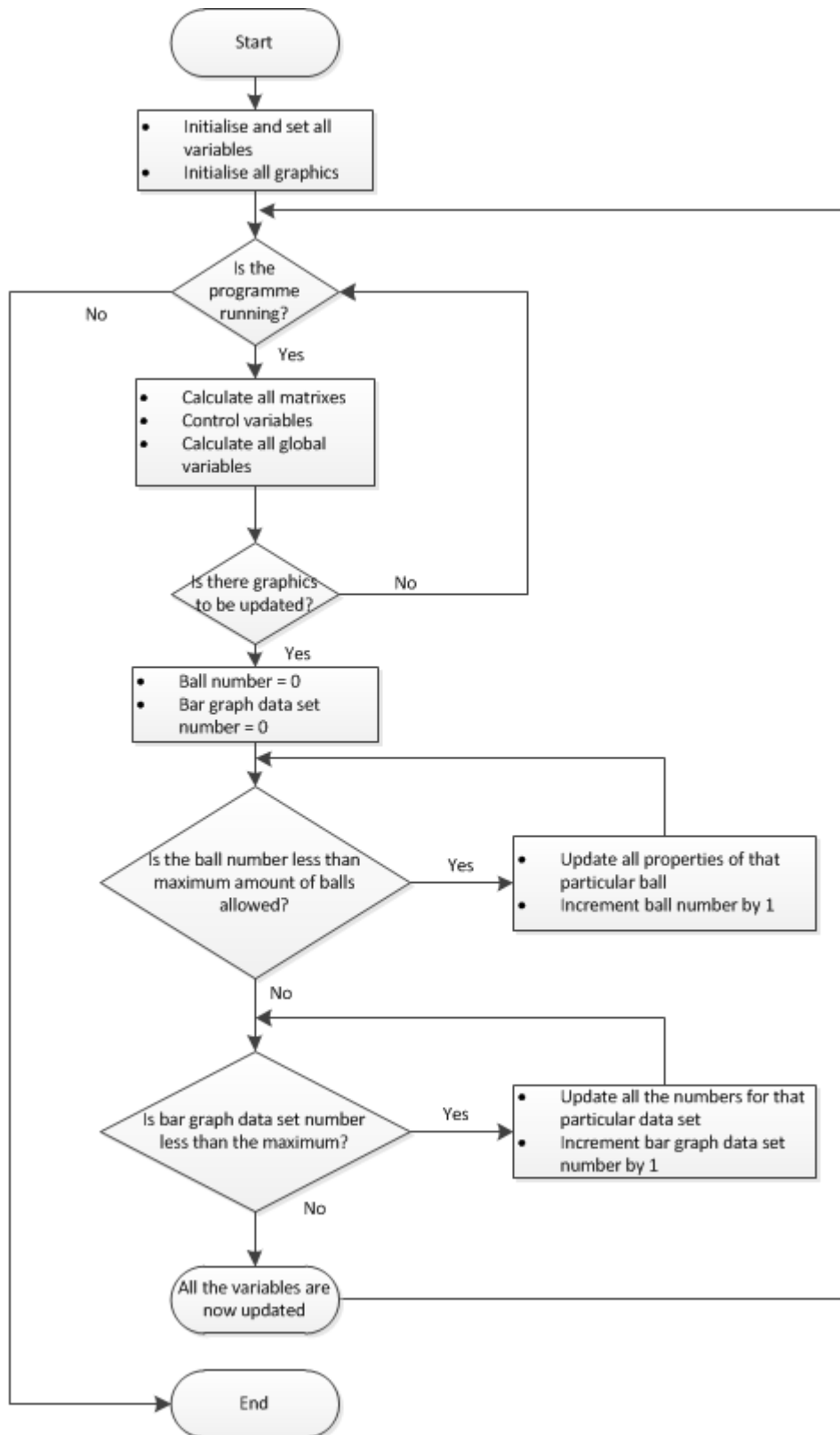


Figure 16: Flowchart of programme's basic structure

C1. Boundaries of molecules

The reactor boundary is the boundary of the molecules. In graphics terms, the sphere (representing the molecule) should not pass over the physical reactor boundary. In a batch reactor, there are four “walls” and each sphere position must be checked that it does not pass through the walls. The direction of the ball is used to find which possible “wall” the molecule can hit (i.e. top, bottom, right or left wall). The x-direction is the horizontal axis and the y-direction is the vertical axis.

Figure 17 shows the particular divisions for the CSTR as the CSTR walls are more complicated than the batch reactor boundaries. The CSTR has an inlet and outlet that the programme must check for. Thus the reactor will be split up in different regions the x-direction and each region will have certain properties. The inlet region will check that the molecules moving up or down will be bouncing off the walls. The ball in the inlet region cannot move beyond the inlet region. The outlet region will do the same in terms of the bouncing up and down the y-direction, but in the x-direction, it will allow the sphere to exit the system. In the reactor region for the CSTR however, the top and bottom walls will be the same as the batch reactor, but the right and left walls will be checked whether they are not touching the inlet or outlet.

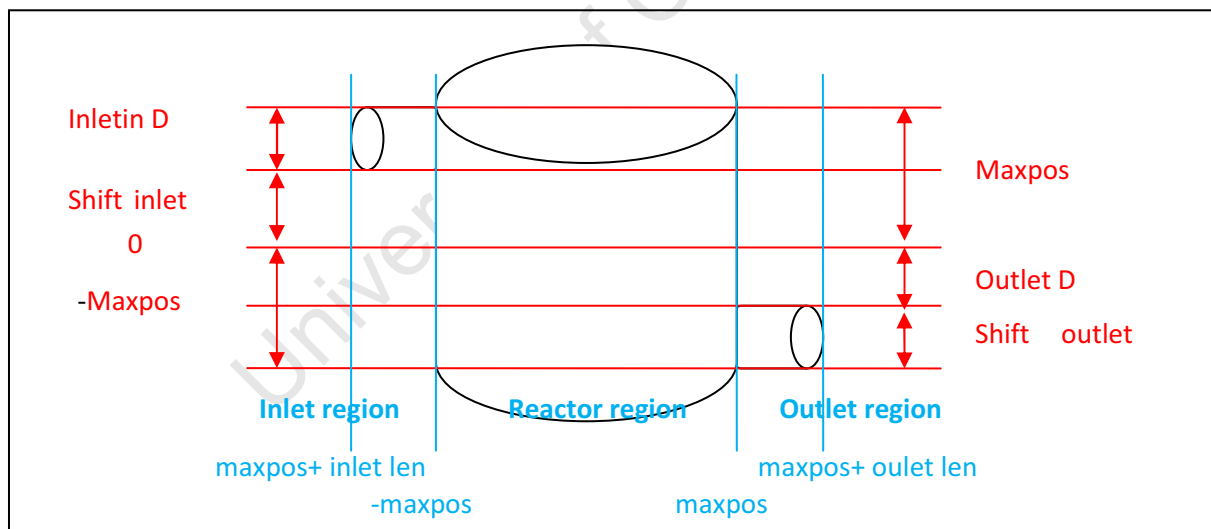


Figure 17: The boundaries of a reactor and their divisions within the programme

A closer look at how the spheres near a boundary will be explained in Figure 18. Ball A is in the inlet region and the ball cannot go past the inlet diameter length. This means that it will bounce off the bottom wall. The direction that will be involved is that the ball is downwards towards the bottom wall then if it touches the bottom wall then it must bounce back up. This means the y-direction is involved.

Ball B is in reaction region and the ball cannot bounce outside the wall. However ball C can go into inlet region. This means reactor region is split into 2 regions when the balls move in the negative x-direction and if it falls below the pipe diameter then it must bounce off the wall and stay in reactor region. But if ball C is following the trajectory to go into the inlet region then ball C will have the same properties of ball A.

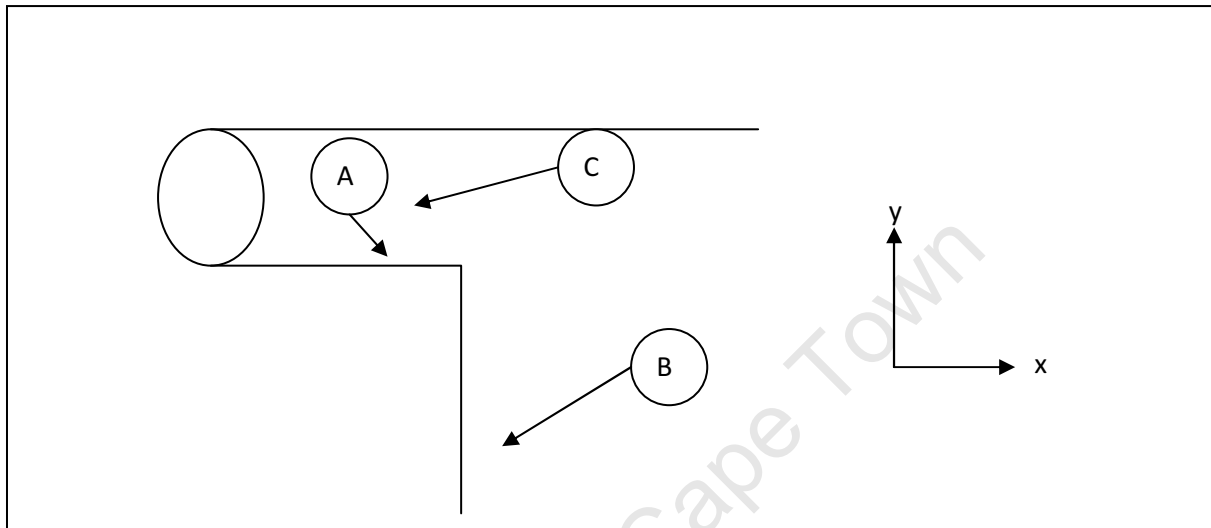


Figure 18: Example of how spheres crossed boundaries

C.2 Timing of molecules released into the reactor

To ensure that the computer does not slow down when the programme is running, a fixed number of spheres have been initialised to minimise memory resources. For a CSTR, there is a flow of molecules coming in and out the reactor, but the number of molecules is not the same for an unsteady state CSTR (for start up). This means that there needs to be a reserve of available spheres for the programme to use so that it can release a sphere into the reactor when the timing is right. But eventually, the number of molecules will run out as there is a fixed number. As there is an outlet of molecules from the reactor, one can “recycle” the sphere back into the reactor for the inlet flow as shown in Figure 19. Before the sphere can be recycled, it enters a reservoir. The reservoir is where all the available spheres are, but they are not seen by the user as they are invisible. The inlet system finds an available sphere in the reservoir and when the time is right, it releases it into the inlet flow

rate.

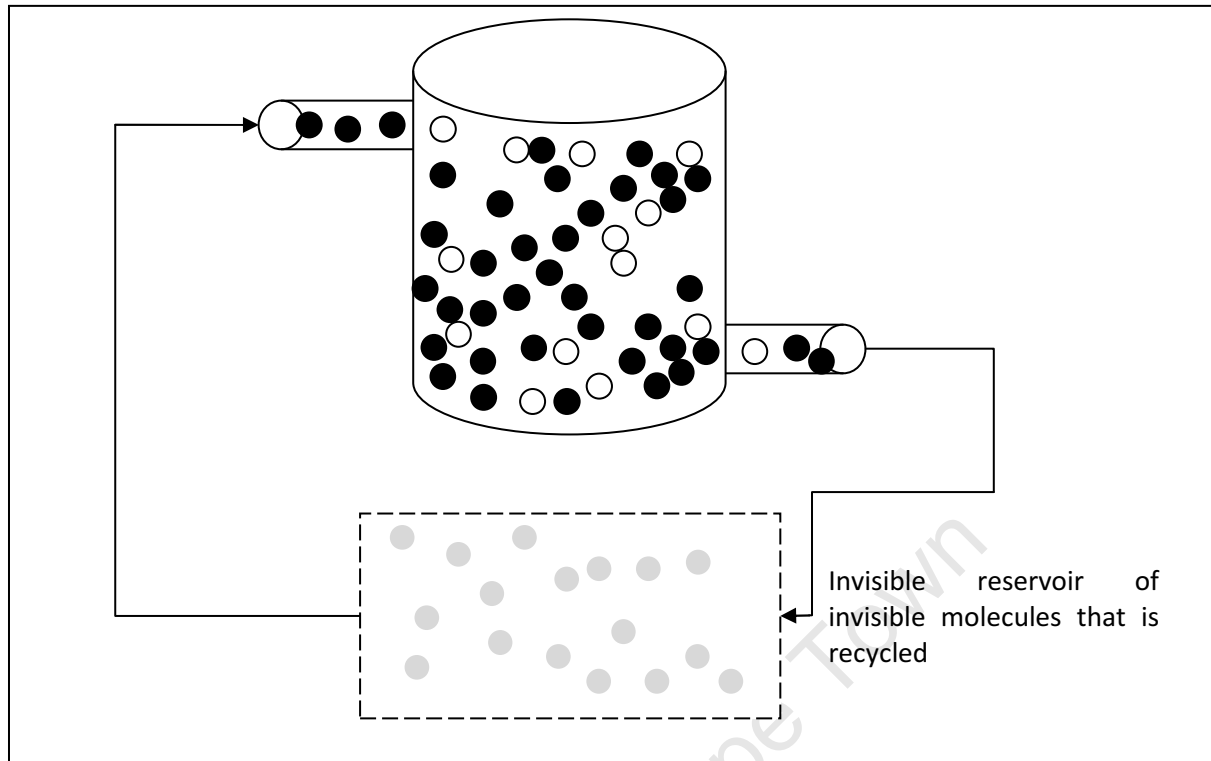


Figure 19: Illustration of how programme recycles spheres using a reservoir

In addition, the programme will also deal with the flow rate into the reactor, which is the rate at which the spheres are released into the reactor. Each step in the while-loop is a time step, and there is a global time which is the sum of all the time steps of the reactor so far. There was a set time delay variable that is inversely proportional to the flow rate. This means that if the flow rate is high, the time delay of the molecule released into the system was short and vice versa.

C.3 Probability of changing from product to reactant

There were two ways to do this using a statistical probability or using the available Reaction Design Equations to determine how many reactant and product are in the reactor. If the conversion of reactant to products is high, then there are more products than reactants and vice versa. However, as the system is also in dynamic equilibrium, there are constant forward and reverse reactions that occur in the reactor.

For the statistical probability, the chance of the molecule converting will be compared to a random number generated by the computer. The chance of the molecule changing is usually quite small, but over many time steps, the chance of the molecule converting will be higher. The forward and

reverse rate each has their separate probabilities and are calculated independent of each other, which will allow for a simulation of the dynamic equilibrium system.

On the other hand, in this animation the number of products and reactants was determined by the mass and energy balance which is shown in Figure 20. Thus, a vector of available number of product and reactant can be made. This vector can be shuffled and the corresponding molecule will either stay as the product/reactant, or change. This will also simulate the dynamic equilibrium system.

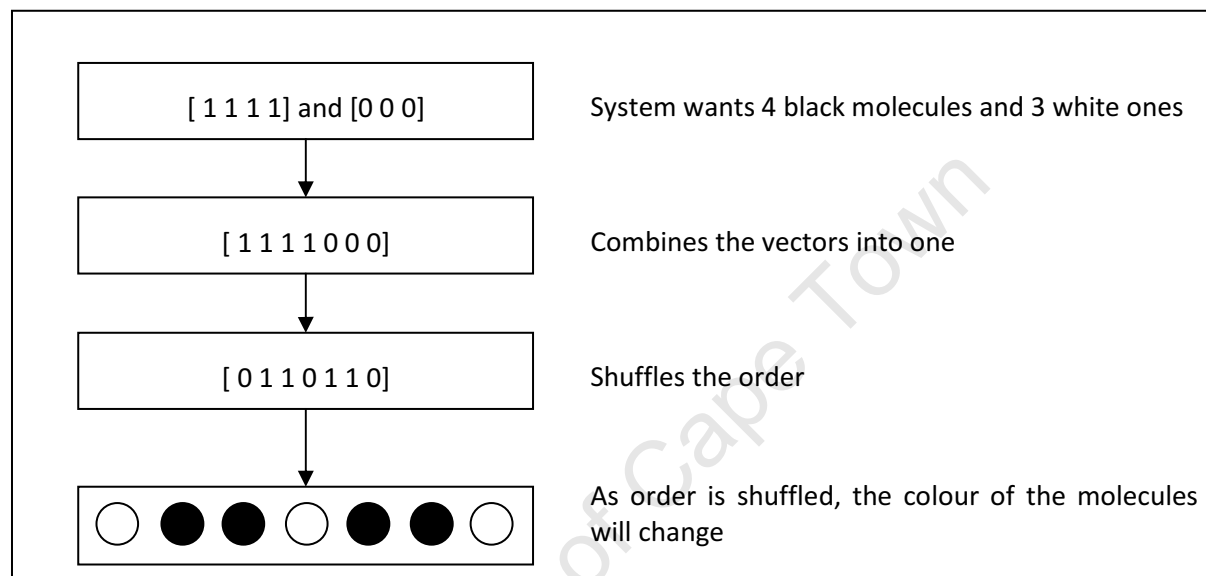


Figure 20: Illustration for dynamic equilibrium calculations that is determined by Mass and Energy Balances

C.4 Bar graphs and line graphs

In terms of showing change over time, bar graphs are easier to construct than line graphs. Bar graphs are made of an axis and rectangle. The rectangle height will change over time corresponding to the variable that is responsible. VPython uses the centre of the object as the x and y position to render, thus the rectangle must be shifted to the correct y-position.

Line graphs, on the other hand, require some vector manipulation as not to slow the computer down as shown in Figure 21. The line graph is actually made of little segments of line that are connected together, but all the positions of the points joining the line must be known. The points on the x axis are known (usually time), but the y values must still be calculated. The line graph updates its information by updating the latest information and discarding the oldest information. This can be seen in the figure below.

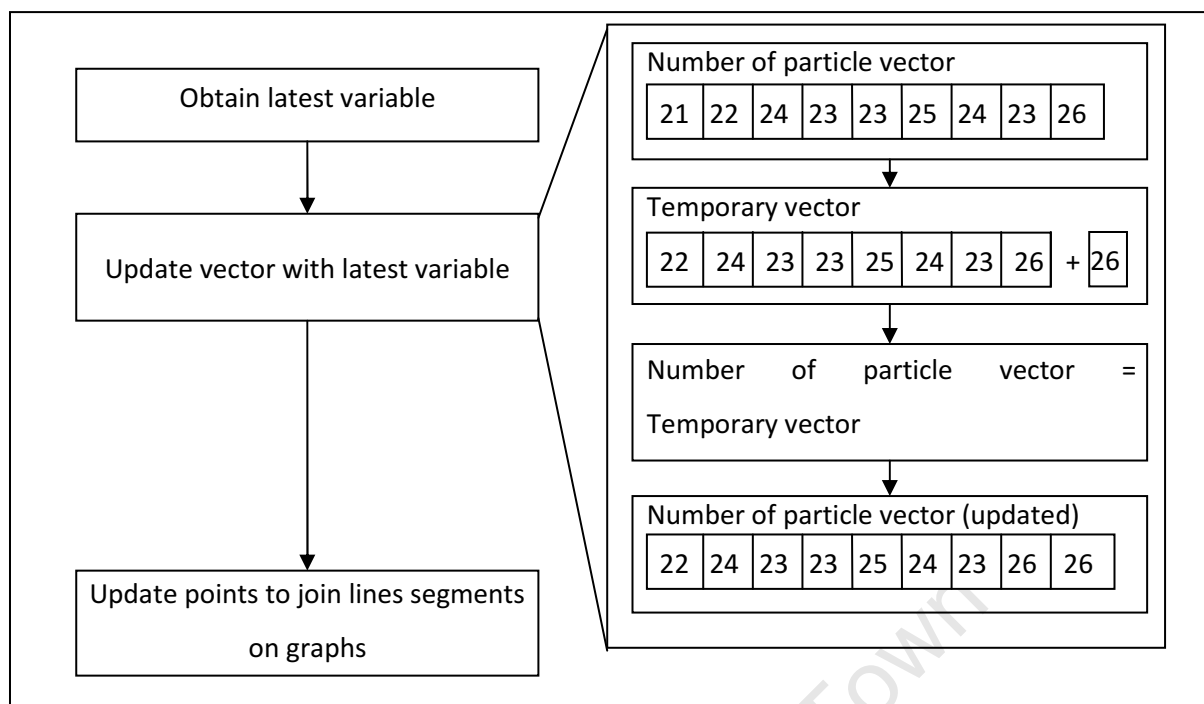


Figure 21: Updating a line segment algorithm

C.5 Buttons

The buttons were coupled together so that the user can cycle up and down the different lesson segments. For instance if the button displayed “Lesson 1” then the whole simulation will jump to the lesson segment on lesson 1 and change the buttons’ text. The buttons were using the current lesson text to determine what text the buttons displayed; this can be seen in Table 11.

Table 11: Investigation 5's navigational buttons

Current Display Text	Up Button Text	Down Button Text
Lesson 1	Start Lesson	Go to Lesson 2
Lesson 2	Back to Lesson 1	Go to Lesson 3
Lesson 3	Back to Lesson 2	Go to Lesson 4
Lesson 4	Back to Lesson3	End of Lessons

C.6 Interactive graph (The X-T graph)

The X-T graph here was a bit different to the one that of Investigation 1 as this one is interactive and can determine the initial conditions of the system. The position of the mouse was read from the screen. If the user’s mouse click position was off the x and y axis, then the programme will detect the closest point to the user’s initial mouse click position. This position will be converted into X and T values and it will update the system.

C.7 Correspond Temperature to colour

Values of temperature were probability too cluttered for the viewer to see, thus colours were used to associate the temperature. Blue means cold and red means hot. This is can be seen in Table 12 below. All these RGB values were interpolated to correspond with the temperature.


Table 12: Temperature and their corresponding values

Temperature(C)	Colour	R	G	B
0	blue	0	0	1
166.6667	turquoise	0	1	1
333.3333	light blue	0.5	1	1
500	white	1	1	1
666.6667	yellow	1	1	0
833.3333	orange	1	0.5	0
1000	red	1	0	0

C.8 Jacket reactor

The Jacket colour and size responded to the sliders associated with the jacket. If the flow of the jacket changed, so did the radius of the jacket walls and its arrows. The top and bottom jacket walls adjusted to fit the size of the jacket. The temperature also changed with the temperature of the jacket.

Appendix D. Ethics procedures

	RESEARCH ACCESS TO STUDENTS	DSA 100
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NOTES

- This form must be completed by applicants that want to access students for the purpose of research. Attach your research proposal.
- Return Completed application forms to: Moonira.Khan@uct.ac.za; or deliver to: Attention: Executive Director, Department of Student Affairs, North Lane, Steve Biko Students' Union, Room 7.22, Upper Campus, UCT.
- The turnaround time for a reply is approximately 10 working days.
- NB: it the responsibility of the researcher/s to apply for ethical clearance to the relevant: (a) Faculty's "Research in Ethics Committee" (RIEC), and (b) to the Executive Director, HR to access staff for research purposes.
- For noting, a requirement of UCT is that items (1) and (4) apply even if prior clearance has been obtained by the researcher/s from any other institution.

SECTION A: PERSONAL DETAILS

Position	Staff / Student Reference No	Title and Name	Contact Details
Student Number	MXXKAR001	Ms. Karen Ma	Mxxkar001@uof.ao.za
Academic / PASS Staff No.			
Visiting Researcher – ID No.			
Contact details of faculty officer for inquiries	Randhir.rawafal@uof.ao.za		
University / Institution at which employed / or a registered student	Registered Student	Address if not UCT:	
Faculty and Department	Engineering and Built Environment – Chemical Engineering		
Division / School / Unit	Modelling group		
APPLICANTS DETAILS	Title and Name	Tel.	Email
	Ms. Karen Ma	021 850 5628	Mxxkar001@uof.ao.za

SECTION B: SUPERVISOR DETAILS

Position	Title and Name	Tel.	Email
Supervisor	Dr. Randhir Rawafal	-	Randhir.rawafal@uof.ao.za

SECTION C: APPLICANTS STUDY FIELD AND TITLE OF RESEARCH PROJECT / STUDY

Degree	Msc. in Chemical Engineering
Research Project / Title	Development of Discrete Element simulated animations for Visualizing Complex Processes in Chemical Engineering Education
Research Proposal attached	Yes <input checked="" type="checkbox"/> attached No <input type="checkbox"/>
Target population	2 courses (Reactor Design I and II: CHE304F and CHE3054S) are targeted and the maximum number students that are willing to participate in my research (i.e. the entire class if they are willing).
Lead Researcher details	The students will be allowed to choose what group they would like to participate in, the control group (that does not use any visualization tools), a short term memory group (to find the effects of the animation tools on short term memory) and a long term memory group (that are constantly willing to use the animation).
Research Methodology and informed consent:	All groups will be participating in short questionnaires after the animation or equivalent chalk-board lecture that take about 15 mins to fill in and a written feedback session that takes about 10 mins to fill in. The animation lecture itself will about 20 mins (for the 2nd group). For the long term memory group, the student can choose how long they want to spend on playing around with the animation. This will happen once a term. We do require the students to give their names for the test but not the questionnaire, on the condition that the results of the test will not be reported with student names (we need to do it this way to cross-correlate results).
Ethical clearance status	The ethics form has been completed and attached to this email

**SECTION D: APPROVAL STATUS – FOR ACCESS TO STUDENTS FOR RESEARCH PURPOSE
(To be completed by the ED, DSA or Nominee)**

APPROVAL GRANTED	Ref. No: MXXKAR001	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>	Comments
APPROVED BY	Title and Name	Designation	Signature
	Ms Moonira Khan	Executive Director Department of Student Affairs	Signed by candidate
			Date:

Appendix E. Calculation of baseline mark

To explain Equation 1, a fictional student will be made up to illustrate how the equation is used. Student "A" took the following courses in his second-year of studying his Chemical Engineering Degree as shown in the table below. He passes everything except for Chemistry II.

Table 13: Example of student's A second core-courses and marks obtained

Course Name	Course credits	Course mark
Chemistry I	24	50
Chemistry II	24	30
Chemical Engineering Laboratory	4	55
Design of Chemical Processes	8	52
Material and Energy Balances	20	60
Mathematics II	32	60
Thermodynamics I	12	60

Student "A" will have to repeat Chemistry II to be able to obtain the course credit. However, he is still able to proceed with the third year courses despite failing one course. In his third year of study, he is able to pass his Chemistry II subject with 30%. And then in his fourth year of study, he finally manages a 50%. UCT's method for calculating academic average is not used in this instance as it takes into account all other courses that the student has done for the year and only takes into account the credits that have been passed. The above equation is used as follows:

$$\frac{(24 \times 50) + (24 \times 30) + (4 \times 55) + (8 \times 52) + (20 \times 60) + (32 \times 60) + (12 \times 60) + \overbrace{(24 \times 30)}^{\text{The extra times}} + \overbrace{(24 \times 50)}^{\text{repeating course}}}{(24 \times 24) + (3 \times 24) + (1 \times 4) + (8 \times 8) + (1 \times 20) + (1 \times 32) + (1 \times 12)} = \frac{8316}{172} = 48.3\%$$

Appendix F. Post-tests questions

The questions are the original questions but the format has been edited to remove all spaces (where the student can write on). Also the mark allocation has been added.

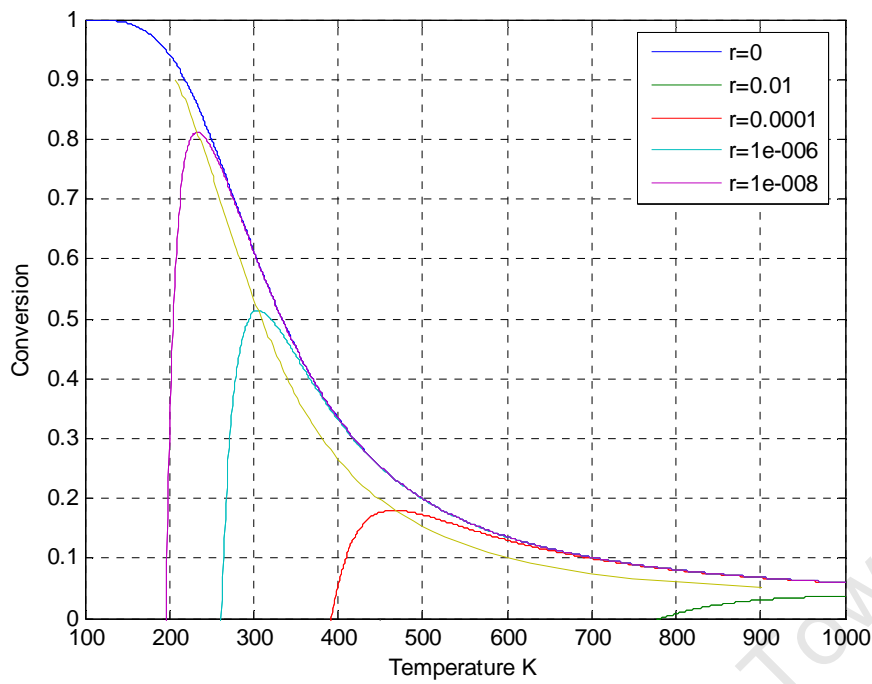
F1. Investigation 1 (Non-isothermal Energy Balance)

[Total marks – 15]

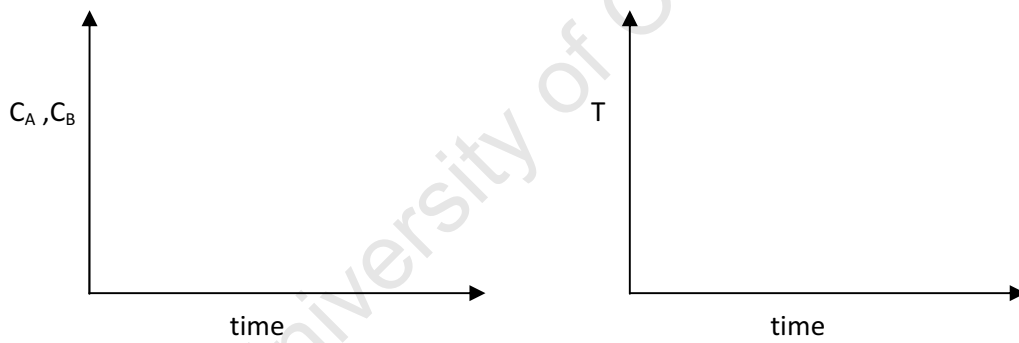
A ⇔ B (Shown on board)

1.1 In the case of exothermic reactions, what becomes of the equilibrium conversion as the temperature rises? Why? (3 marks)

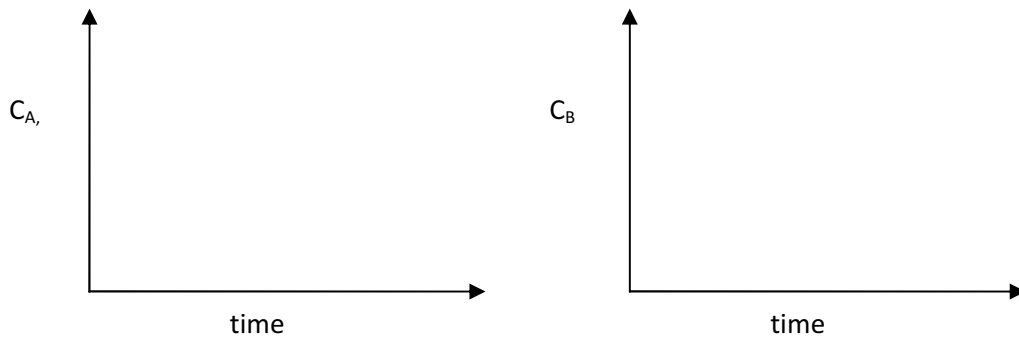
Refer to the X-T plane provided.



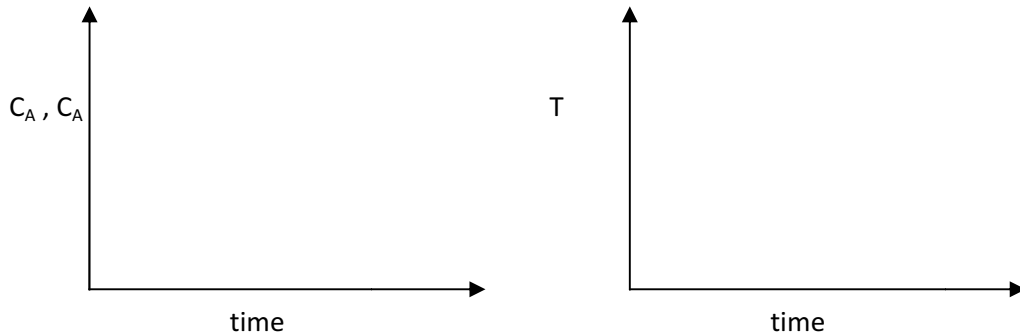
1.2 Let's say the system started from equilibrium at a temperature of 300°C and was forced to a temperature of 700°C. Sketch the C_A , C_B and temperature-time profiles. **(2 marks)**



2.1 If the system initially contains pure reactant A at a temperature of 300°C Sketch the C_A , C_B and temperature-time profiles. Pay attention to the end-values. **(2 marks)**

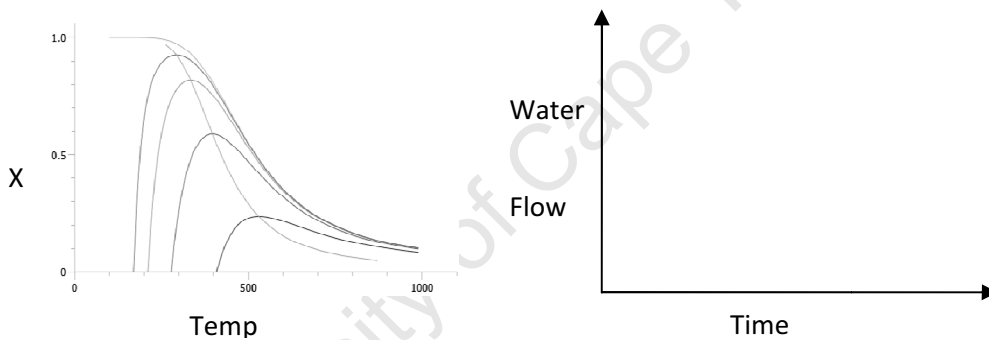


2.2 If the system starts with pure product B at a temperature of 1000°C sketch the C_A , C_B time profiles. Pay attention to the end-values. **(2 marks)**

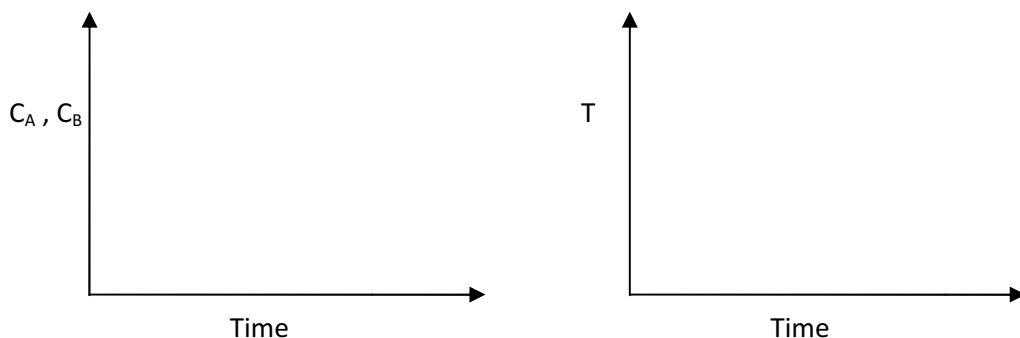


3.1 What is the purpose for a jacketed reactor? How does it help with conversion? **(2 marks)**

3.2 Identify the maximum rate path (Circle it). Sketch (very rough) the expected change in flow rate required to remain on the maximum rate path if the system is initially at pure-A at 210°C and the jacket is 300°C. **(2 marks)**



3.3 Sketch concentration, temperature-time profile if system is initially pure-A at 210°C if an infinitely large jacket fluid flow rate occurred. (Jacket is at temperature of 300°C). What would the concentration-time profile look like? Explain briefly **(0 marks as question was removed as too many questions)**

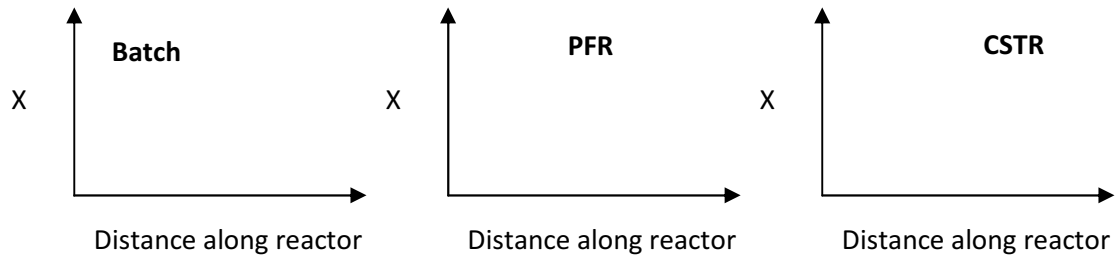


F2. Investigation 2 (Basic Reactor Design)

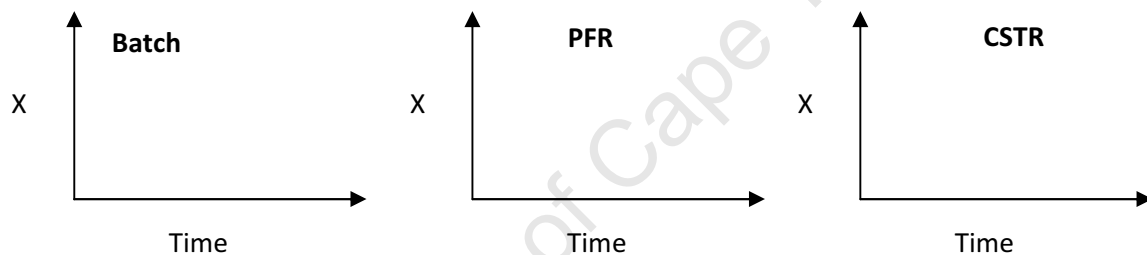
[Total Marks – 36]

1. Explain in your own words the physical meaning of batch reactor, plug flow reactor, continuous stirred tank reactor. Sketch pictures with your explanations as needed.

2. Sketch the conversion-distance profiles for each of the three reactor types. (3 x 2 marks)



3. Sketch the conversion-time profiles for each of the three reactor types. (3 x 2 marks)



4. Which reactor gives the best reaction rate? Why? (2 marks for reactor, 2 marks for each reason)

5. Which reactor gives the worst reaction rate? Why? (2 marks for reactor, 2 marks for each reason)

6. Explain the influence of flowrate in each case. How would you decide which flowrate would give you the best production rate? (2 marks for each reactor, 2 marks for reason)

F3. Investigation 3 (Reversible reactions)

[Total marks – 23]

Question 1

- Explain your understanding of an elementary rate law. How is it different from a non-elementary rate law? (3 marks)
- Write the rate law for $2A \rightleftharpoons 3B + C$ and write down order for each component if the reaction was elementary and reversible. (3 marks)

- c. Explain the difference between the intrinsic probability of the reaction happening and the extent to which it happens. Using the rate expression in b) above, point out which variables relate to which concept. (Hint: Refer to analogy but do not use example) **(4 marks)**

Question 2

Generally speaking, the rate constant for the forward reaction is different to that for the reverse. Consider a first order forward and a first order reverse reaction ($A \rightleftharpoons B$)

- a. If system starts with pure A in the reactor, sketch the concentration profile when i) $k_f > k_r$, ii) $k_f = k_r$, iii) $k_f < k_r$ **(3 x 2 marks)**
 b. How is it possible in reactor design to improve the rate so that the net rate is in the favour of wanted component? **(2 marks for each reason)**

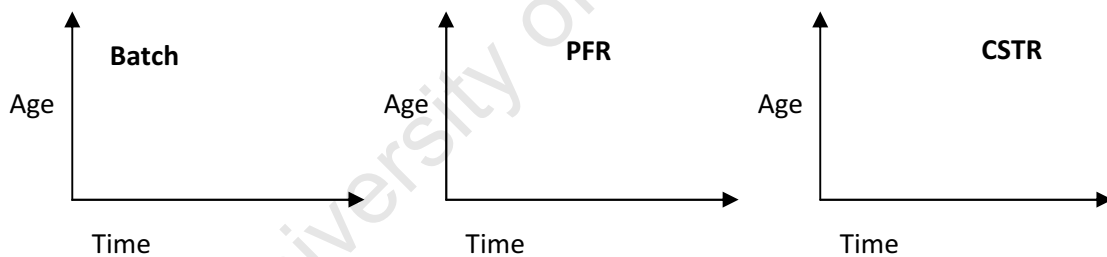
Question 3

Elementary rate laws for a batch reactor will result in some sort of equilibrium. How will it differ in a CSTR? **(3 marks)**

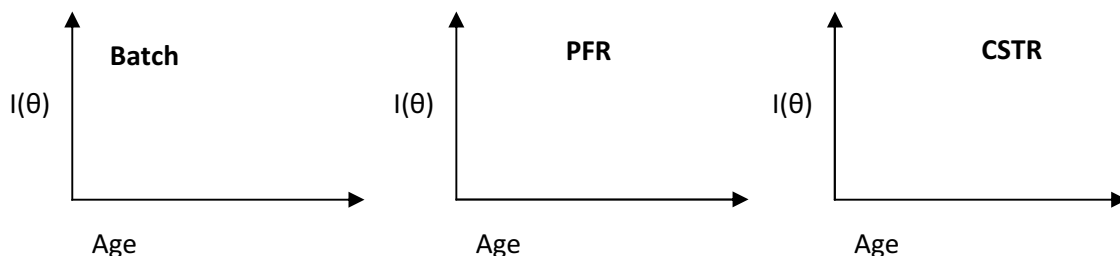
F4. Investigation 4 (Residence Time Distribution)

[Total marks – 28]

1. Sketch how age varies with real time. (Sketch the age –time graph for tracer aging inside a PFR, CSTR and Batch after a certain t_0 .) **(3x1 marks)**



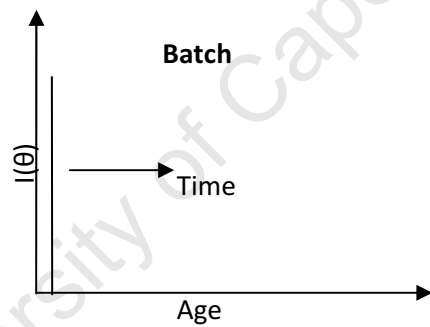
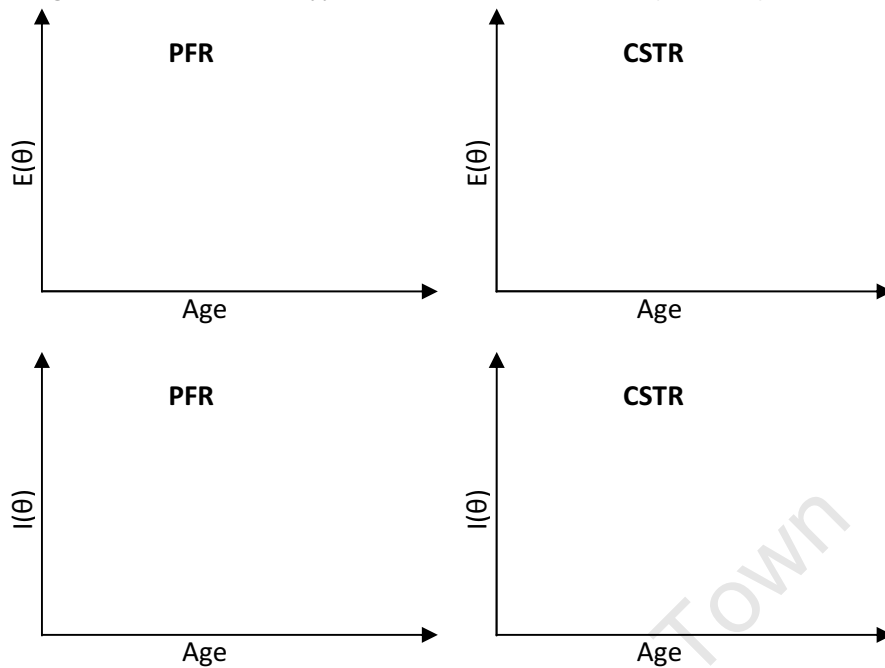
2. Sketch and describe how a pulse of tracer will distribute across the reactor for $I(\theta)$. **(3x2 marks)**



3. Please explain how **larger volumes** and **higher flowrates** separately affect the age distribution in each reactor. **(3 marks)**

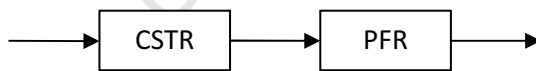
- 3.1. On the figures provided below, sketch $E(\theta)$ and $I(\theta)$ curves for **ideal cases** of the PFR and CSTR. (Use solid lines —) **(5 marks)**

3.2. On the same figures, sketch $E(\theta)$ and $I(\theta)$ curves for **high volumes and low flowrates** through the three reactor types. (Use dashed lines -----) (4 marks)

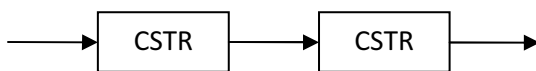


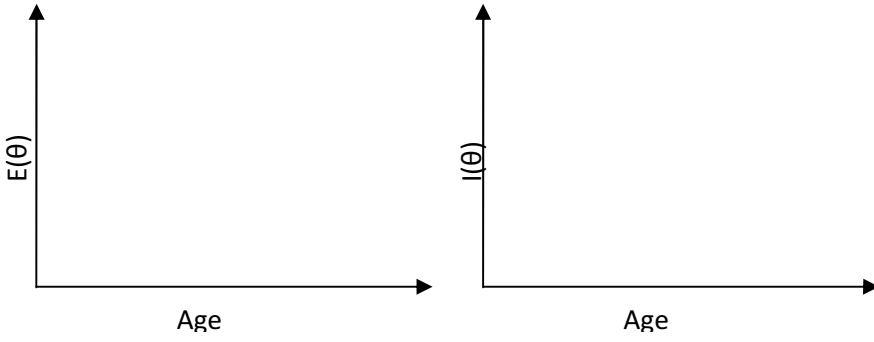
4. Sketch for the following reactor networks ($E(\theta)$ and $I(\theta)$) on the same set of axes provided below.

4.1. Use dashed lines (---) (2 marks)



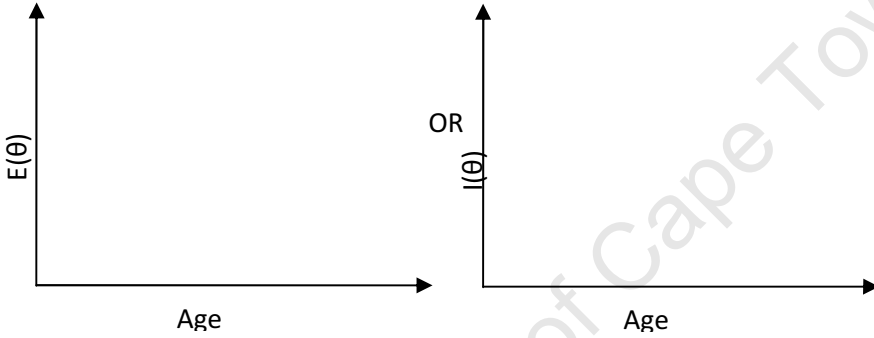
4.2. Use solid lines (—) (2 marks)





4.3. Explain what the internal RTD for the tracer in each series network would look like and how would the time delay in pipe have an effect on the RTD. **(3 marks)**

5. If we have a recycle, what would the internal OR external RTD look like? Sketch and explain each iteration of your thought pattern. If you do not explain this iteration, no marks will be awarded. **(0 marks, question was removed as lecturer thought it was too difficult)**

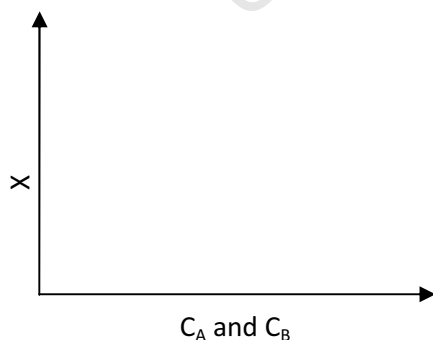


F5. Investigation 5 (Non-isothermal Energy Balance)

[Total marks – 20]

A ⇔ B (Shown on board) X and T relationship

1. Draw a graph of conversion (X) vs C_A (—) and C_B (----) for 1st order reactions. **(2 marks)**

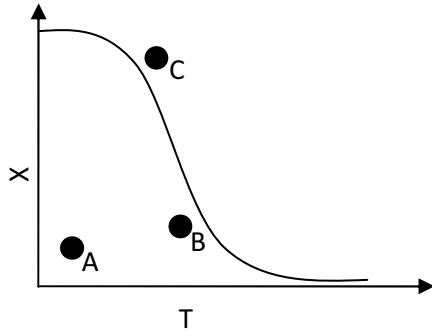


2. How does Temperature relate the motion of the particles? What does this mean to individual reaction rates? **(2 x 2 marks)**

Isorate lines

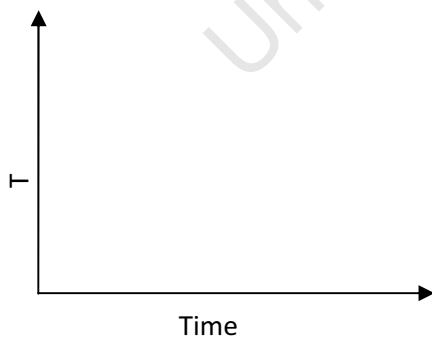
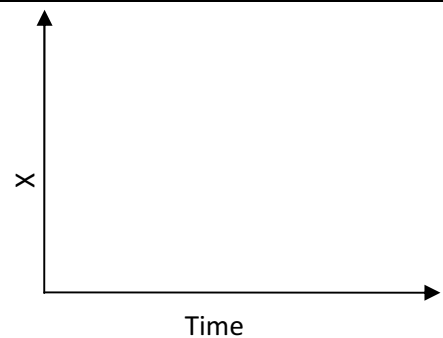
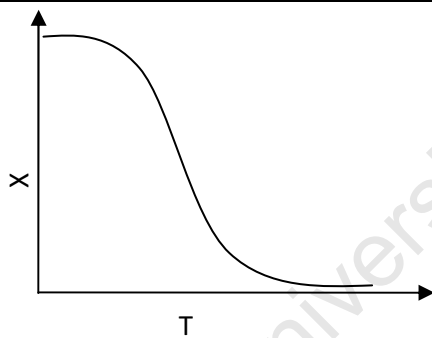
3. I) Explain how temperature (T_{system}) affects the net reaction rate. (2 marks)
 II) Explain how overall conversion (X_{system}) affects the net reaction rate. (2 marks)

Which has higher reaction rates among the reactions given on the graph below? (3 marks)



Adiabat

4. Along the adiabat line, the higher temperature (exothermic), the reverse reaction rate is increasing more than the forward reaction rate. Plot adiabat line for batch on a X-T plane and sketch X(Time) and T(Time) curves and explain. (2 marks for adiabat and 1 marks for each other graph)



Jacket

5. If all reactor systems return to equilibrium, what is the purpose of a jacket reactor? (3 marks)

Appendix G. Questionnaire questions

For Likert-scale questions (i.e. all of question 1 and question for all questionnaires) where 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly Agree

G1. Animation group questions

Investigation 1 (Non-isothermal Energy Balance)

1. Did you find the animation enjoyable?

1	2	3	4	5
---	---	---	---	---

2. Did the animation help you understand the concepts that are in equilibrium conversion?

1	2	3	4	5
---	---	---	---	---

3. There will be another a home version uploaded onto Vula. Would you use it? Y/N. If you choose to use it, how much time would you estimate to spend on it?
4. What aspects of the animation did you enjoy?
5. What aspects of the animation lecture do you wish to improve?
6. There will be another animation lecture soon, what aspects would you like the animation to focus on?

Investigation 2 (Basic Reactor types)

1. Did you find the animation enjoyable?

1	2	3	4	5
---	---	---	---	---

2. Did the animation help you visualise the concepts in basic reactors?

1	2	3	4	5
---	---	---	---	---

3. If you were able to take the animation home to use, would you use it?
4. What aspects of the animation did you enjoy?
5. What aspects of the animation lecture do you wish to improve?
6. Would you like another animation lecture and what concepts would you like the animation to focus on?

Investigation 3 (Reversible Reactions)

1. Did you find the animation enjoyable?

1	2	3	4	5
---	---	---	---	---

2. Did the animation help you visualise the concepts in reversible reactions?

1	2	3	4	5
---	---	---	---	---

3. If you were able to take the animation home to use, would you use it?
4. What aspects of the animation did you enjoy?
5. What aspects of the animation lecture do you wish to improve?
6. Would you like another animation lecture and what concepts would you like the animation to focus on?

Investigation 4 (Residence Time Distribution)

1. Did you find the animation enjoyable?

1	2	3	4	5
---	---	---	---	---

2. Did the animation help you visualise the concepts in RTD?

1	2	3	4	5
---	---	---	---	---

3. What aspects of the animation did you enjoy?
4. What aspects of the animation lecture do you wish to improve?
5. Do you have difficulties telling the difference between the color red and green? Or with blue and yellow?
6. Out of previous lectures with Dr. Rawatlal and myself, do you prefer animation lecture or a normal lecture?
7. Would you like another animation lecture and what concepts would you like the animation to focus on?
8. Animations have been uploaded to vula. Have you used any of these animations? And if so, did these animations help you?

Investigation 5 (Non-Isothermal Energy Balance)

1. Did you find the animation enjoyable?

1	2	3	4	5
---	---	---	---	---

2. Did the animation help you visualise the concepts in reversible reactions?

1	2	3	4	5
---	---	---	---	---

3. What aspects of the animation did you enjoy?
4. Do you prefer normal lectures or animations lectures?

5. What can be improved in this animation lecture?

G2. Control group questions

Investigation 1 (Non-isothermal Energy Balance)

The students in the control group were asked ignore the word “animation” in this questionnaire and focus only on the animation.

1. Did you find the animation enjoyable?

1 2 3 4 5

2. Did the animation help you understand the concepts that are in equilibrium conversion?

1 2 3 4 5

3. There will be another a home version uploaded onto Vula. Would you use it? Y/N.
If you choose to use it, how much time would you estimate to spend on it?

4. What aspects of the animation did you enjoy?

5. What aspects of the animation lecture do you wish to improve?

6. There will be another animation lecture soon, what aspects would you like the animation to focus on?

Investigation 2 (Basic Reactor Types)

1. Did you find the lecture enjoyable?

1 2 3 4 5

2. Did the lecture help you visualise the concepts in basic reactors?

1 2 3 4 5

3. Would you prefer watching an animation instead of having a classroom lecture?

4. If you were allowed to take an animation home, would you prefer that to reading notes?

5. Would you like an animation lecture and what concepts would you like the animation to focus on?

6. Please put other comments here.

Investigation 3 (Reversible Reactions)

1. Did you find the lecture enjoyable?

1 2 3 4 5

2. Did the lecture help you visualise the concepts in reversible reactions?

	1	2	3	4	5
--	---	---	---	---	---

- Would you prefer watching an animation instead of having a classroom lecture?
- If you were allowed to take an animation home, would you prefer that to reading notes?
- Would you like an animation lecture and what concepts would you like the animation to focus on?
- Please put other comments here.

Investigation 4 (Residence Time Distribution)

- Did you find the lecture enjoyable?

1	2	3	4	5
---	---	---	---	---
- Did the lecture help you visualise the concepts in RTD?

1	2	3	4	5
---	---	---	---	---
- Out of previous lectures with Dr. Rawatlal and myself, do you prefer animation lecture or a normal lecture?
- Would you like a normal lecture that is supplemented with animations and what concepts would you like the animation to focus on?
- Animations have been uploaded to vula. Have you used any of these animations? And if so, did these animations help you?
- After completion of this test, animations will be shown to you. Do you think you would have enjoyed being in the animation lecture?

Investigation 5 (Non-isothermal Energy Balance)

- Did you find the classroom lecture enjoyable?

1	2	3	4	5
---	---	---	---	---
- Did the lecture help you visualise the concepts in Non Isothermal Energy Balance?

1	2	3	4	5
---	---	---	---	---
- Do you enjoy normal lectures without any animations?
- If you enjoy the normal lectures, do you think having animation lecture will help you with understanding the content better?

Appendix H. Example of instructions on how to use animations

Instructions on how to download Vpython:

1. Go to http://vpython.org/contents/download_windows.html
2. Download version: Python 2.6(Scroll down page a little bit)
3. The instructions on the page are:
First, download and install [Python-2.6.6](#) (**Important: Let it install in C:\Python26**)
(There is not a VPython version for Windows 64-bit Python)
Second, download and install [VPython-Win-Py2.6-5.60](#)
4. Please click on the link themselves.
5. And follow instructions as listed in instruction number 3.

NB: This is for Window version only!!!! If you would like other versions for mac:

http://vpython.org/contents/download_mac.html

Opening of files and running of file

Make sure you install python first. After python and Vpython is BOTH installed, then can continue with the following instructions.

To open files, just press File>Open and wherever you have placed the file.

Press F5 and the programme will run. To close the programme press the x in the corner of programme or press close.

Please note that that these simulations are written for a 19" screen. If your screen is smaller then, just resize the windows.

Basic reactor types (1st simulation) Filenames

Batch – batchfinal.py

PFR – PFR.py

CSTR – CSTRfinal.py

Reversible reactions (2nd simulation) Filenames

Dice analogy –diceanalogyonyellow.py

Reversible elementary reactions –Batchreversible.py

Reversible elementary reactions for $A \rightleftharpoons 2B$ – stoichreversible.py

If there is anything that you need help with or what you think could be improved in the simulation, feel free to email me at Karen.ma@uct.ac.za. For 1st simulation (or Basic reactor types) if you want your test script back, please email me if you have written your name on the test script by the 24th March so I can give it back to you before the mid-term test. For the 2nd simulation (or Reversible reactions), a copy of your tests(if you put your name on script) will be marked as soon as possible.

University of Cape Town