Microbiology Honours Students' Conceptual Development during a Beer Brewing Teaching Learning Sequence (TLS)

By

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For my family;

Your support, love and motivation,
hugely contributed towards this journey.
Thank you for believing in me.

Preface

The research described in this thesis was carried out in the Discipline of Biochemistry, School of Biochemistry, Genetics and Microbiology, University of KwaZulu-Natal, Pietermaritzburg campus, from January 2009 to December 2010 under the supervision of Professor Trevor R. Anderson and Mr. Charles Hunter.

The work presented in this thesis represents the original work of the author and has not been otherwise submitted in any other form for any degree or diploma to any other University. Where use has been made of the work of others, it has been duly acknowledged in the text.

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Abstract

Brewing is defined as "the combined processes of preparing beverages from the infusion of sound grains that have undergone sprouting, and the subsequent fermentation of the sugary solution produced, by yeast-whereby a proportion of the carbohydrate is converted to ethanol and carbon-dioxide." It is a complex process that requires knowledge of concepts from disciplines such as biochemistry, chemistry, engineering, microbiology and physics. The micro-brewery apparatus at the University of KwaZulu-Natal is used by the discipline of microbiology as part of a brewing exercise to introduce students to industrial microbiology with the aim of developing their conceptual understanding of the process. So far, though, no research has been conducted in order to fully establish the effectiveness of this exercise in developing such understanding of the brewing process. The aim, therefore, of this study was to investigate the effectiveness of a micro-brewing Teaching-Learning Sequence (TLS) that incorporates the micro-brewery, for promoting students' understanding of the scientific concepts of relevance to the brewing process. The following research questions were addressed: 1) What concepts are essential for understanding the process of beer brewing? 2) Did those students with sound conceptions develop deeper understanding during the TLS? 3) Did students show any conceptual difficulties with the brewing concepts? 4) Did any remediation of such difficulties occur during the TLS? 5) Did students show retention of (mis)understanding two months after the brewing practical? 6) What were students' attitudes and motivational levels like during the brewing practical? 7) How well did students rate their experiences of the whole TLS? 8) How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding? The study involved ten microbiology honours students subjected to a TLS which consisted of: i) three brewing lectures aimed at introducing students to the brewing process; ii) pre- & post tests including concept mapping tasks aimed at addressing research questions 2, 3 & 4; iii) a brewing practical aimed at facilitating students' development of mental models and conceptual understanding of the brewing process and their motivation and attitude to this exercise (addressing question 6 & 8); iv) a group discussion which involved a group tasting session and the evaluation and discussion of each group's final beer product; v) semi-structured interviews to establish the source (s) of students' difficulties and their retention of knowledge or difficulties (questions 2, 4, & 5 addressed); and vi) an evaluation questionnaire aimed at obtaining student opinion of the TLS (addressing question 7). The data obtained was analyzed via inductive analysis. The results revealed the following brewing difficulties: i) belief that glycolysis reactions are non-consecutively linked chemical reactions which are independent of one another; ii) confusion that whirl-pooling cools the wort; and iii) belief that the final specific gravity value is a measure of the amount of sugars converted to ethanol. Comparison between the pre- & post test responses indicated that some students' (B, D & K) conceptual understanding including integrated knowledge of the brewing process improved during the TLS and their brewing difficulties were remediated. In contrast, other students' (A, C, E, G, H, J & I) conceptual understanding did not improve during the TLS and their brewing difficulties were not remediated. There was also a positive correlation between student attitudes and motivation towards the brewing practical and the quality of their learning outcomes. Students (B, D & K) who showed high motivational levels and cognitively and physically took part in the TLS showed improved conceptual understanding of the brewing process and retention of knowledge, while those showing low motivational levels did not improve. Furthermore, there are students (G, H & J) who showed high motivational levels during the TLS but their conceptual understanding of the brewing process did not improve. The results obtained suggest that the TLS, based on the micro-brewery apparatus, was at least partially effective in facilitating the development of students' conceptual understanding and visualization of the brewing process and the remediation of some of their difficulties, which in some case correlated well with their motivational levels and attitudes towards the brewing exercise. More research is however required to fully confirm the usefulness of such TLSs in brewing education.

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Abbreviations

TLS	Teaching Learning Sequence
ERs	External Representations
UKZNP	University of KwaZulu-Natal, Pietermaritzburg
SABTI	South African Brewing Training Institute
DMUKZNP	Department of Microbiology at the University of KwaZulu-Natal, Pietermaritzburg
SMM	S-Methyl-Methionine
DMS	Dimethylsulfide
OG	Original Gravity
FG	Final Gravity
SAB	South African Breweries
SOI	Selecting Organizing Integrating
CCM	Conceptual Change Model
DRF	Developmental Research Framework
IDF	Ingénierie Didactique Framework
ED	Epistemological Dimension
PCD	Psycho-Cognitive Dimension
DD	Didactic Dimension
PCA	Principal Component Analysis
NAD^+	Nicotinamide adenine dinucleotide
( )	Words added by the researcher for the purposes of adding meaning to the students' responses.
[..]	Ellipse showing omitted section of the students' text

Chapter 1: Introduction, Aims and Research Questions

Ascribed as the world's oldest beverage, beer has been in existence since the 4th millennium BC (Hornsey, 1999). Scientific and archaeological evidence indicates beer was first produced by Sumerians in southern Babylonia (Hornsey, 1999) and at that time, most brewers were women. Beer was mainly brewed for religious ceremonies and its nutritional and "mood altering" properties[1] (Hornsey, 1999). Moreover, in Egyptian societies, where beer brewing started 3000-5000 years ago, beer was i) used to treat different illnesses, ii) offered as a gift, iii) used as currency, and iv) mainly used in ritual and religious ceremonies[1] (Hornsey, 1999; Meussdoerffer, 2009). Furthermore, literature shows the process of beer brewing greatly increased during the rise of Christianity. This is because i) Charlemagne, the Christian emperor considered beer to be vital for living[1] and monks played major roles in beer brewing. Additionally, monks were amongst the first people to brew beer for business purposes because they needed money to provide food and shelter for travelers and pilgrims[1]. Interestingly, fasting monks were allowed to have five litres of beer a day and beer was only brewed in autumn and winter (Herholdt, 2010).

Sumerians made beer from baked barley bread and water. The baked barley bread was ground and mixed with water and the product was considered as beer (Cobb, 2010). In addition, literature indicates that as early as the year 1067, water, malted barley and hops were used for brewing. However, prior to the year 822, gruit (a mixture of herbs) was used instead of hops[1]. Yeast was only introduced after 1857[1]. Before industrialization, beer was brewed and sold on a domestic scale, however, after the industrial revolution, brewing industries were built and this marked the beginning of brewing and selling beer on a large scale. Although various types of beer have been developed over the years, the four main ingredients, namely, water, malted barley, hops and yeast have and are still being used for making beer. Furthermore, the introduction of hydrometers and thermometers has enabled brewers to control and manipulate the brewing process[1].

[1] http://en.wikipedia.org/wiki/History_of_beer

The brewing process has also become more complex as more steps have been added in order to improve the quality and taste of beer. To date, there are about ten steps (Section 2.1.3) involved in the brewing process. Under each step, there are different parameters that have to be controlled in order to ensure a successful brew; such parameters include temperature, pH and time. Furthermore, the process of brewing encompasses concepts (Section 3.7) from disciplines such as biochemistry, chemistry, engineering, microbiology and physics. Therefore, knowledge of these concepts is important in understanding the biotechnology of beer brewing.

Research has established that students have various misconceptions (Section 2.6), which, if not remediated, may hinder the learning of correct scientific concepts (Gilbert *et al.,* 1982; Armstrong, 1995; Odom, 1995; Howitt *et al.,* 2008; Özmen *et al.,* 2009). Various researchers have identified numerous student misconceptions in biology (e.g. Barman *et al.,* 2003; Bulunuz, *et al.,* 2008), chemistry (e.g. Wu *et al.,* 2000; Nicoll, 2001) and physics (e.g. Oberle *et al.,* 2005; Lee and Kwok 2009). Limited studies have been conducted on student difficulties in biochemistry (e.g. Anderson and Grayson, 1994) and general microbiology (e.g. Alparslan *et al.,* 2003; Finlay, 2005). However, no research has been carried out to investigate students' difficulties with the brewing process. Thus this study aims at identifying students' brewing difficulties and using a teaching-learning sequence (TLS) to help remediate the observed brewing difficulties and develop students' conceptual understanding of the brewing process.

External representations (ERs) are mostly used in the teaching and learning of science because they are important for knowledge construction (Peña and Quílez, 2001; Treagust *et al.,* 2002), and promote conceptual understanding of abstract phenomena (Kozma, 2000; Schönborn and Anderson, 2009). One example of ERs usually used as teaching and learning tools are models. Models improve learning (Chittleborough *et al.,* 2005), and explain concepts and processes (Treagust *et al.,* 2002). The micro-brewery apparatus is an example of a model used by various Universities (e.g. University of Wisconsin) as a teaching and learning tool (Waechter-Brulla and Woller, 2000). This is important because in order to fully understand the brewing process, students ought to develop their mental models and visual skills with regards to this process. The

University of KwaZulu-Natal on the Pietermaritzburg campus (UKZNP) has been using the micro-brewery apparatus as a teaching and learning tool for the past seven years. However, no research has been done in order to investigate the effectiveness of this model in promoting students' conceptual understanding of the brewing process. Therefore, the overall aim of the current research is to track any change in Microbiology honours students' conceptual development during a beer brewing TLS based on the micro-brewery apparatus. To achieve this goal, the following research questions were addressed:

1. What concepts are essential for understanding the process of beer brewing?
2. Did those students with sound conceptions develop deeper understanding during the TLS?
3. Did students show any conceptual difficulties with the brewing concepts?
4. Did any remediation of such difficulties occur during the TLS?
5. Did students show retention of (mis)understanding two months after the brewing practical?
6. What were students' attitudes and motivational levels like during the brewing practical?
7. How well did students rate their experiences of the whole TLS?
8. How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding?

The first research question is addressed in Chapter 3, whereas the remaining research questions are dealt with in Chapter 4. Chapter 2 describes the literature relevant to the current study and provides a more detailed motivation for performing the research. Furthermore, an overview of the methodology employed to address the above research questions is discussed in Chapter 3. The overall results are presented in Chapter 4 whereas general discussions of the work presented in this thesis, implications of the results and future improvements of the study, are discussed in Chapter 5. To facilitate clarity and ease of reading, an overview of the study is provided in fig. 1 below.

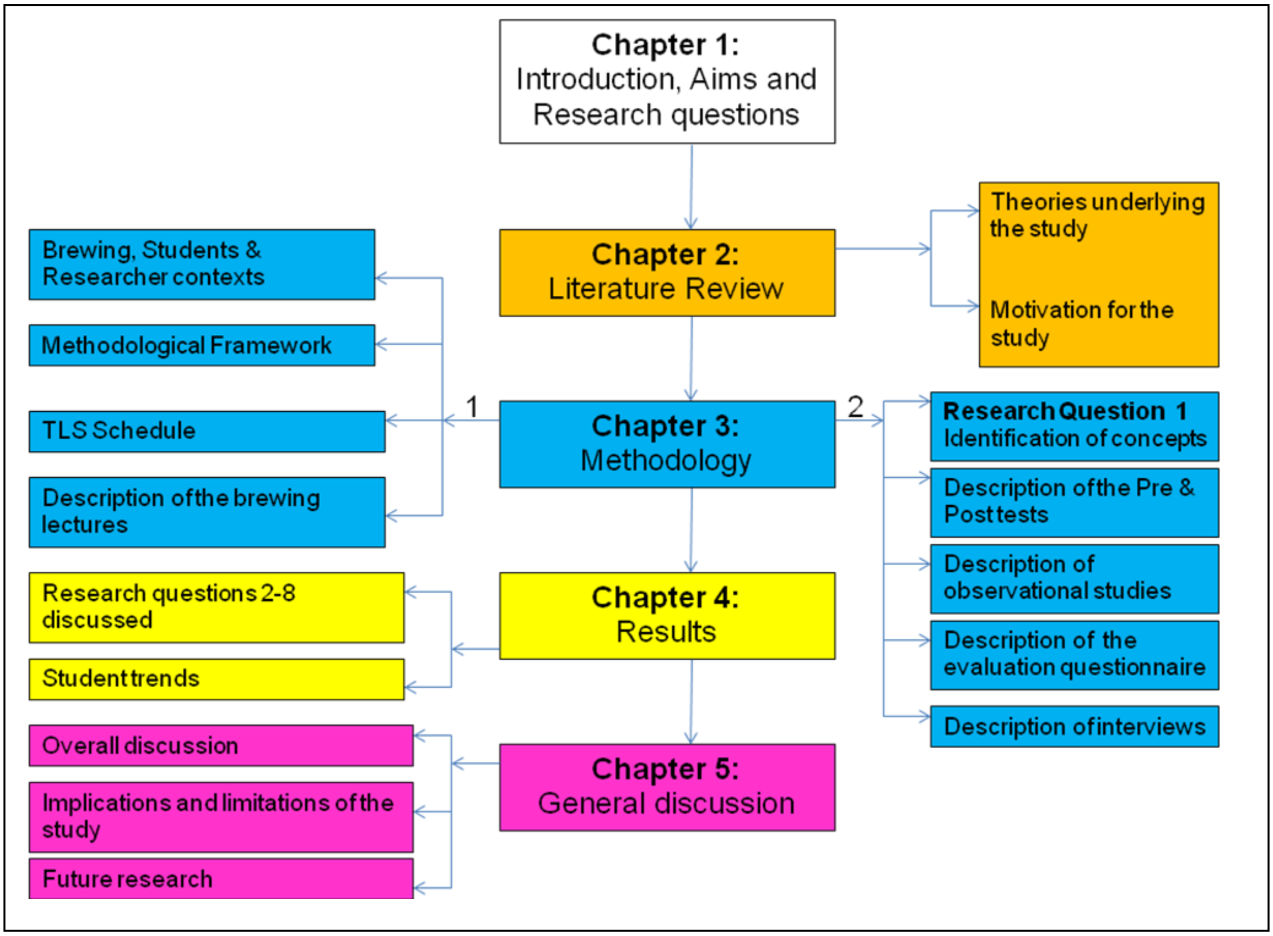


Figure 1: Overview of the study.

Chapter 2: Literature Review: Theoretical Framework

The process of beer brewing is complex and requires knowledge of concepts from disciplines such as biochemistry, chemistry, engineering, microbiology and physics. Due to this, various institutions (e.g. Wisconsin University, SABTI and UKZNP) use the micro-brewery apparatus for teaching the biotechnology of beer brewing (Waechter-Brulla and Woller, 2000; Herholdt, 2009). However, to date, no research has been done on the effectiveness of micro-breweries in enhancing students' conceptual understanding of the brewing process. Thus, the goal of this study was to explore the efficacy of a brewing TLS based on the micro-brewery apparatus in developing microbiology honours students' conceptual understanding of the brewing process.

The literature reviewed in this chapter was carefully selected for its relevance to the present project and therefore is intended to serve as a theoretical framework for the study. The theoretical framework is crucial in every study because it outlines and discusses the theories that frame, guide and underpin every aspect of the research. In the present study the major components of the theoretical framework were published research pertaining to brewing (Section 2.1), the importance of laboratory work (Section 2.2), models as learning tools (Section 2.3), theories and models of learning (Section 2.4), the meaning of conceptual understanding (Section 2.5), the nature of students' difficulties (Section 2.6) and conceptual change theory (Section 2.7). These are discussed in this chapter and shown how they relate to the goals and performance of this project.

2.1 Brewing Theory

2.1.1 Historical Background

According to Salyers (2005), microbiology is a crucial branch of biology that has led to many discoveries such as the germ theory of disease, antibiotics, vaccines and fermentation. Furthermore, microbiologists have recently indicated the importance of bacteria and archaea to human health, revealed the diversity of microbes, introduced PCR and plant biotechnology, and synthesized enzymes for detergent industries. Although microbiology has greatly contributed to the “experimental scientific world”, microbiologists are concerned about student perceptions of microbiology. Many students perceive microbiology as “boring and old fashioned” (Salyers, 2005) whereas some have a misconception that all microbes are harmful to human beings (Taras, 2003). This is due to the fact that in the past, microbiology courses were taught in a way that focused on the harmful effects of microbes to human. To change this perception, microbiologists have increasingly introduced curricula that highlight and emphasize the beneficial roles of microbes to humans and the environment in general (Taras, 2003). For instance, Kingsborough Community College in New York has begun teaching students about antibiotic producing and oil degrading microbes in order to demonstrate the importance of microbes in producing compounds and enzymes used in industries (Taras, 2003). In addition to these topics, the department of Microbiology at the University of KwaZulu-Natal in Pietermaritzburg (DMUKZNP) also teaches students about the importance of micro-organisms for the production of food, beer, and drugs (medicine).

2.1.2 Brewing Ingredients

As stated, the theory and practice of beer brewing is included in one of the courses offered at the DMUKZNP. The aim of the course is to illustrate the importance and role of micro-organisms such as yeasts in industrial scale bioprocesses. Brewing is defined as “ the combined processes of preparing beverages from the infusion of sound grains that have undergone sprouting, and the subsequent fermentation of the sugary solution produced, by yeast-whereby a proportion of the carbohydrate is converted to ethanol and carbon-dioxide” (Hornsey, 1999). The main ingredients used in conventional beer brewing are, malted barley, water, hops and yeast (Ingledew and Hysert, 1994; Hornsey, 1999; Erbe and Brückner 2000; Brooks *et al.,* 2002; Line, 2008). Adjuncts such as maize, sorghum, rice, wheat, rye and oats are sometimes used in conjunction with barley (Herholdt, 2010).

Barley is used because it is a good source of starch and enzymes (Pelter and McQuade, 2005) which degrade starch into fermentable and non-fermentable sugars. Furthermore, barley produces good extract and beer, it has all the nutrients that yeast needs for growth and metabolism and has a husk that is used as a filtering material during lautering (Herholdt, 2010). Barley is steeped, germinated and kilned before being used for brewing (Hough, 1982; Herholdt, 2010). During steeping, barley is immersed in water for about 48 hours (Goldammer, 2008). This is done in order to increase the water content from 12% to around 45% (Hornsey, 1999). The increased water content initiates respiration in the embryo and hydrates the stores of starch in the embryo (Hornsey, 1999; Goldammer, 2008). The moist barley is allowed to germinate for 3-7 days. During germination, gibberellins stimulate the production of hydrolytic enzymes such as amylolytic enzymes, (alpha and beta amylases), which degrade starch. Proteolytic enzymes break down proteins (Kunze, 1999). Once the desired enzymes are produced and most of the cell components have been degraded by glucanases, germination is stopped and the moist green malt is kilned to reduce moisture, develop colour and flavour compounds (Kunze, 1999; Herholdt, 2010). Temperatures used in kilning depend on the type of malt to be produced, that is, amber malts are kilned at 140 °C whereas dark malts are kilned at temperatures up to 220°C (Herholdt, 2010).

Water constitutes about 94% of beer and affects its appearance and taste (Ingledew and Hysert, 1994; Goldammer, 2008). As a result, water used for brewing must be of drinking quality, clear and colourless, free of microbes, pesticides and heavy metals (iron and copper) (Herholdt, 2010). Naturally, water is either hard or soft based on mineral salt composition. Hard water is beneficial because it results in dark beer; however, excessive hardness raises the pH of sparging water. This is a disadvantage because it leads to the leaching of polyphenols which later cause beer haze (Hough, 1982). On the other hand, soft water is preferred for the production of pale ales or lagers (Herholdt, 2009). Hard and soft water have various amounts and types of mineral salts; therefore, breweries treat water in order to alter its ionic concentrations depending on the type of beer to be produced (Goldammer, 2008). Water treatment processes involving for example sand filters, activated carbon, reverse osmosis and ion exchangers are used to produce brewing liquor (Herholdt, 2010).

Hops are one of the most important ingredients because, i) they give beer its characteristic flavour and aroma (Stevens *et al.,* 1999; Stevens and Page, 2004), ii) act as anti-microbial agents (De Keukeleire, 2000; Sakamoto, 2003; Jaskula *et al.,* 2008), and iii) improve foam stability (Kunze, 1999; De Keukeleire, 2000; Van Nierop, 2004). Hops contain α-acids and essential oils (Jaskula *et al.,* 2008); however the proportion of the components depends on the type of hops. For instance, bittering hops will have a high proportion of alpha-acids and a smaller proportion of essential oils, whereas aroma hops will have a high percentage of essential oils and a smaller percentage of alpha-acids.

Alpha-acids are insoluble in cold wort hence bittering hops are added once boiling of the wort has commenced. During boiling, these alpha-acids are isomerized into iso-alpha-acids which add bitterness to the final beer product (Ingledew and Hysert, 1994; Stevens *et al.,* 1999; Okada and ITo, 2001; Malowicki and Shellhammer, 2005; Jaskula *et al.,* 2008). Aroma hops on the other hand are added shortly before boiling is stopped. This is done so as to preserve the aroma since the essential oils they contain are highly volatile (Kunze, 1999).

Yeasts of the species *Saccharomyces cerevisiae* and *Saccharomyces pastorianus var cerevisiae* are used in brewing because they can convert fermentable sugars to ethanol and carbon-dioxide (Ingledew and Hysert, 1994; Herholdt, 2010). Two types of yeast strains are used in beer brewing- top fermenting (for ales) and bottom fermenting (for lagers) yeasts (Herholdt, 2010). Top fermenting yeasts rise to the surface during fermentation and flocculate on top of the fermented wort after fermentation (Dengis, 1997; Kunze, 1999). These yeasts ferment at higher temperatures (15-20ºC) and are allowed to ferment for 5-6 days (Herholdt, 2010). Bottom fermenting yeasts settle at the bottom of the fermentation vessel after fermentation is complete (Ingledew and Hysert, 1994; Kunze, 1999), ferment at slightly lower temperatures (5-10ºC), and fermentation is usually completed within 7-12 days (Herholdt, 2010). It is also important to state that yeast have an essential requirement for nitrogen compounds and zinc for protein synthesis (Kunze, 1999); as well as oxygen for growth and synthesis of sterols and lipids required for cell membrane formation (Raines, 2009). Additionally, potassium and sodium are required for activating enzymatic reactions and transporting substances through the cell membrane whereas phosphate is needed for the formation of high energy substances (Kunze, 1999).

Adjuncts such as oats, maize, rice, rye, sorghum and wheat are sometimes used in conjunction with barley as an additional starch source (Briggs *et al.,* 2004; Herholdt, 2010). Adjuncts which are readily available and inexpensive are commonly used (Kunze, 1999; Li *et al.,* 2005; Herholdt, 2010); they can also contribute to the colour and flavour of beer (Kunze, 1999).

2.1.3 Brewing Stages

There are about ten stages (fig. 2) involved in the brewing process namely, milling, mashing, lautering, wort boiling, whirl-pooling, wort cooling, fermentation, maturation, filtration and packaging (Ingledew and Hysert, 1994; Herholdt, 2010). Knowledge of these processes, their impact on each other and the final product is crucial for understanding the brewing process. Therefore, this study aims at developing students' understanding of these processes during a brewing TLS based on the micro-brewery apparatus.

Milling

Malted barley is milled in order to crack or crush barley husk casings so as to expose starch[2] and break down the endosperm to release enzymes (Herholdt, 2010). The enzymes break down starch to fermentable and non-fermentable sugars during mashing. During milling, it is important to ensure that the husk is intact because it is

[2] http://www-foodsci.ucdavis.edu/bamforth/basics.html

used as a filter material in lautering (Kunze, 1999; Herholdt, 2010). The milled barley is referred to as the “grist” (Kunze, 1999).

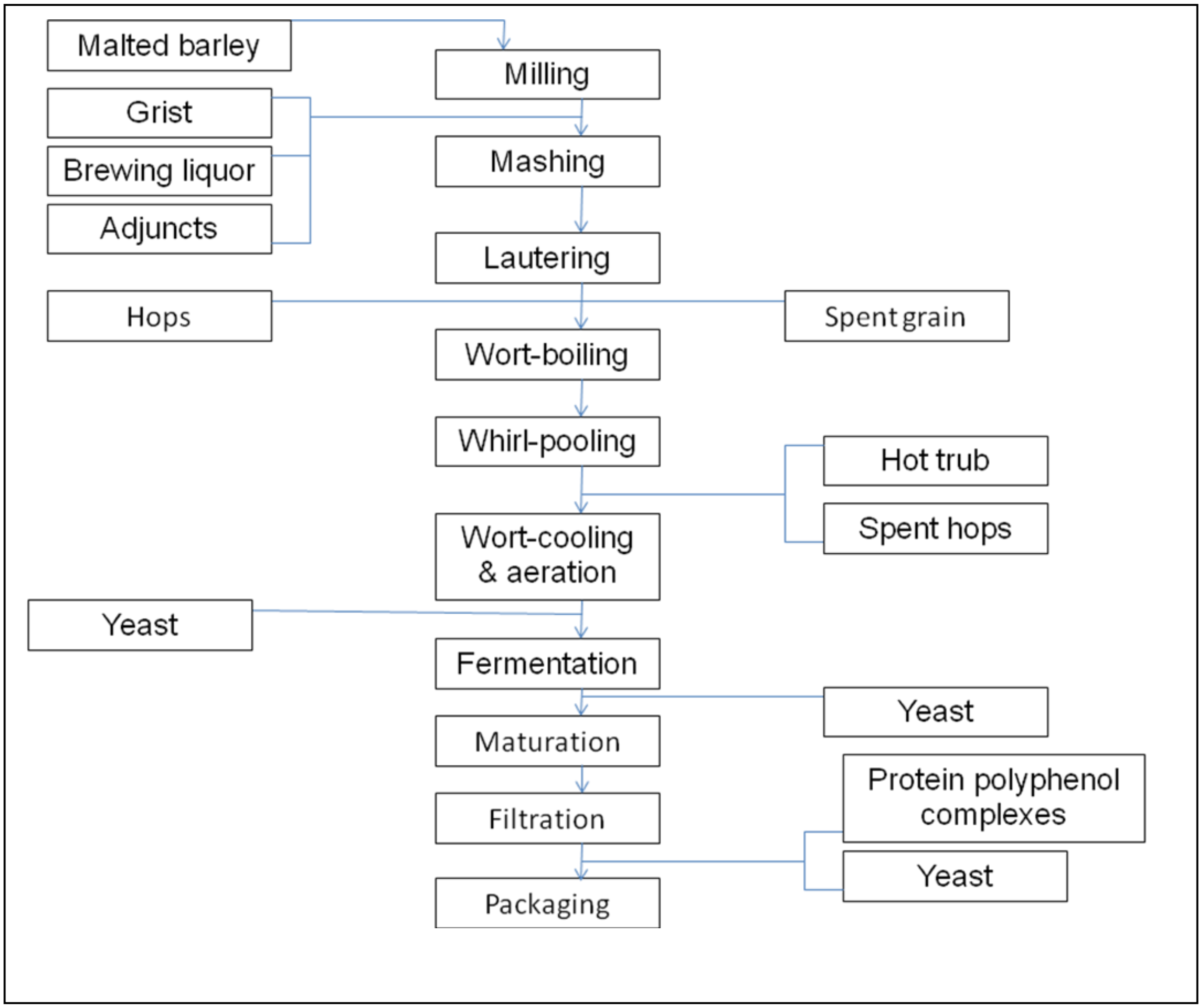


Figure 2: Overview of the brewing process: input materials are on the left side, output materials are on the right side. *Adapted from Willaert, (2007).*

Mashing

The grist contains insoluble substances, such as starch, which cannot be converted to alcohol and carbon-dioxide during fermentation. The purpose of mashing is therefore to convert insoluble substances to soluble substances, such as sugars, which can be used during fermentation (Ingledew and Hysert, 1994). Mashing is controlled by different enzymes (Muller, 1991), as shown in table 1, and enzyme activity is highly dependent on temperature, pH and time (Kunze, 1999; Herholdt, 2010). Enzyme activity increases with increasing temperatures, and this occurs till specific optimum temperatures are reached. Enzyme activity rapidly decreases if temperatures are increased beyond optimum temperatures (Kunze, 1999). This is due to the fact that at higher temperatures, the three dimensional structure of enzymes unfolds hence they are denatured (Kunze, 1999). The fact that enzymes are optimally active at different temperatures is considered an advantage to the brewer. The reason being mashing temperatures and the degree of rest periods influence the composition of the wort (Willaert, 2007), therefore, they can be manipulated depending on the beer style a brewer wants to produce (Muller, 1991). Enzyme activity is also influenced by pH. Different enzymes are optimally active at specific pH values, as shown in table 1, while increasing pH above optimum denatures enzymes (Kunze, 1999). Mashing activity influences the body and alcohol content of beer, the amount of peptides and amino acids in the wort, the pH of the wort, the β-glucan content in the beer, the colour and clarity of beer (Willaert, 2007).

During mashing, alpha and beta amylases, limit dextrinases, maltases, and saccharases degrade starch into dextrins and sugars (MacGregor, 1996; Stenholm, 1999; Pelter and McQuade, 2005; Willaert, 2007); peptidases convert proteins into amino acids; and glucanases degrade cell walls components into β-glucans and β-glucanes. Three processes occur during starch degradation: gelatinization, liquefaction and saccharification (Ingledew and Hysert, 1994; Kunze, 1999). Gelatinization occurs when starch granules absorb a large amount of water, swell, burst, and form a viscous solution. This sets free the starch molecules hence, they are more easily attacked by enzymes (Kunze, 1999; Mousia, 2004). In liquefaction alpha-amylase breaks down amylose and amylopectin into small chains, hence decreasing the viscosity of the gelatinized starch (Kunze, 1999). During saccharification, alpha-amylases continue to break down starch into dextrins, non-fermentable sugars and a small proportion of fermentable sugars (Pelter and McQuade, 2005). Beta-amylases degrade starch into maltose (Pelter and McQuade, 2005); limit dextrinases break down the 1,6 bonds in starch into dextrins; and maltases degrade maltose into glucose (Willaert, 2007).

Table 1: Enzymes active during mashing. *Adapted from Willaert, (2007).*

Enzymes	**Optimum Ph**	**Optimum temperature** (°C)	**Inactivation temperature** (°C)	**Hydrolysis reaction**	**Product**
Starch degradation					
Beta Amylase	5.4-5.6	57-65	70	alpha 1,4 bond, non reducing end	maltose
Alpha Amylase	5.5-5.8	65-70	75	alpha 1,4 bond	dextrin
Limit dextrinase	5.1-5.5	55-60	65-70	alpha 1,6 bond	dextrin
Maltase	6.0	35-40	40	maltose	2 glucose
Saccharase	5.5	50	55-67	saccharose	glucose & fructose
Protein degradation					
Endo-peptidase	5.0-5.5	40-60	60-80	Peptide bond, inside chain	Short peptidases
Carboxy-peptidase	4.8-5.6	50-60	70	Peptide bond at carboxy end	Amino acids
Amino-peptidase	7.0-7.3	40-45	50-55	Peptide bond at amino end	Amino acids
Dipeptidase	8.8-8.8	40-45	50	dipeptide	2 amino acids
Degradation of cell wall components					
Endo β-1,4 glucanase	4.5-5.0	40-45	50-55	β- 1,4 bond	β- glucan
Endo β-1,3 glucanase	4.6-5.5	60	70	β- 1,3 bond	β- glucane
β glucane solubilase	6.3-7.0	62-70	73	Bond between β- glucane and protein	β- glucan
Endo & Exo xylanases	5.0	45	-	Pentosan (hemicelluloses): xylan chain	xylose

Protein degradation also occurs during mashing. Proteins are degraded by carboxy-peptidases, aminopeptidases and dipeptidases into amino acids (Willaert, 2007). These enzymes are optimally active at different temperatures, table 1. Products formed during proteolysis are crucial because they are utilized by yeast for growth, and they influence the colour and foam of the final product, beer (Willaert, 2007). Degradation of cell wall components also occurs during mashing. Beta-glucans and hemicellulose found in cell walls are degraded into β-glucanes and xylose by endo-β-glucanases, β- glucan solubilases and endo-xylanases (Willaert, 2007). These enzymes have an important role because they reduce haze and filtration problems that can arise during the brewing process (Willaert, 2007).

The conversion of starch to fermentable sugars during mashing can be monitored using a simple iodine test which stains starch dark blue. Mashing is complete once all the starch present has been converted to sugars. This is followed by raising the temperature to 76°C in order to deactivate mashing enzymes.

Lautering

Mash consists of spent grains and wort. Spent grains consist of husk, seedlings and other insoluble materials (Kunze, 1999; Willaert, 2007), whereas wort is the liquid fraction and consists of dissolved non-fermentable and fermentable sugars (Kunze, 1999). Wort is used for beer production hence it must be separated from the spent grains. The spent grains and the husk are used as filtering materials (Kunze, 1994; Herholdt, 2010). During lautering, mash is transferred to the lauter tun where filtration of the wort occurs. Once the first wort-running has been drained off, spent grains are sparged with water in order to wash out more dissolved sugars. Sparging dilutes the wort, and it is important to make sure that sparging is halted before the overall specific gravity of the wort is lowered too much. This is done in order to avoid the leaching out of tannins which can later contribute to the formation of haze in beer. Furthermore, it is crucial to ensure that the sparging water is warm and not too hot, the force of sparging water is not high, and the water used for sparging is soft. Hot water and high force result in the leaching of undesirable polyphenols and silicates. Polyphenols form complexes with proteins which later contribute to the formation of beer haze. Hard water contains carbonates and bicarbonates which act as weak bases and raise the pH of sparges (Findlay, 1971). High pH results in the draining of polyphenols which contribute to the formation of beer haze (Findlay, 1971).

Wort boiling

Wort is boiled in the kettle for 1-2 hours (Briggs *et al.,* 1982). During boiling the following important processes occur: wort sterilization, inactivation of malt enzymes, isomerization of hop components, caramelization of sugars, formation and precipitation of protein polyphenols, acidification of wort, and removal of unwanted volatiles (Royston, 1971; Briggs *et al.,* 1981; Ingledew and Hysert, 1994; Kunze, 1999; Virkajarvi, 2001; O'Rourke, 2002; Priest and Stewart, 2006; Willaert, 2007; Eßlinger, 2009; Herholdt, 2010). The reasons why these processes are important are as follows:

- ❖ Wort sterilization: unboiled wort contains micro-organisms which can affect the flavour and taste of the final product (Priest and Stewart, 2006). Therefore to avoid this, wort is boiled at 102-103°C in order to kill micro-organisms (Royston, 1971).

- ❖ Inactivation of malt enzymes: it is possible that the lautered wort still has amylolytic enzymes. If these enzymes are allowed to pass into the fermentor vessel they would cause amylosis which results in the production of "dry beer with low nutritional value" (Royston, 1971; Ingledew and Hysert, 1994). Therefore, wort boiling destroys all malt enzymes that might still be present in the wort.

- ❖ Isomerization of hop components: two types of hops are added during boiling. Bitter hops are added at the beginning of the boil while aromatic hops are added shortly before boiling is stopped. During boiling, alpha-acids are isomerized to iso- alpha-acids which are bitter and give beer a bitter flavour (Briggs *et al.,* 1981; Kunze, 1999; De Keukeleire, 2000; Van Nierop *et al.,* 2004; Malowicki and

Shellhammer, 2005; Elena *et al.,* 2008; De-Schutter *et al.,* 2008). The level of bitterness produced depends on the duration of boiling, the size of hop fragments (milled hops gives higher yields), the pH of the wort (higher pH results in higher yields whereas yields at lower pH are more balanced and finer), and the type of isohumulone used (high yields are obtained from the cohumulone) (Willaert, 2007). Since aromatic hops contain highly volatile oils (Kunze, 1999) they are added towards the end of the boil in order to retain the aroma (Kunze, 1999).

- ❖ Caramelization of sugars: during boiling, the colour of the wort becomes darker (Willaert, 2007). This is due to the so called Maillard or browning reactions that occur between reducing sugars and amino acids via Schiff bases to ketoses (Royston, 1971; De-Schutter *et al.,* 2008). The ketoses decompose to reductones which react with amino acids to form aldehydes that have characteristic flavours (Royston, 1971). Furthermore, aldehydes react with amino acids to produce melanoidins which increase the colour of the wort (Ingledew and Hysert, 1994).

- ❖ Denaturation and coagulation of proteins: Proteins are denatured by high temperatures. During boiling, whirl-pooling also takes place and it encourages hot break. During hot break, the denatured proteins are coagulated and settled at the bottom of the kettle. This is important because it minimizes the formation of protein polyphenol complexes thereby reducing the formation of beer haze.

- ❖ Acidification of wort: calcium present in brewing liquor reacts with phosphates from the malt to from calcium phosphate (Royston, 1971). During boiling, calcium phosphate precipitates and this lowers the pH of the wort (Ingledew and Hysert, 1994). In addition, wort pH is lowered due to the presence of hop acids, and the formation of melanoidins (Willaert, 2007). Low wort pH is favoured because it encourages precipitation of protein polyphenol complexes while most spoilage micro-organisms do not tolerate acidic conditions (Kunze, 1999; Lowe and Arendt, 2004).

- Removal of unwanted volatiles: S-methylmethionine (SMM) is a precursor of dimethylsulfide (DMS) formed during malting (Willaert, 2007). DMS is unfavoured in brewing because it gives beer a corn like smell and taste. During boiling SMM is converted to DMS which evaporates as it is highly volatile.

Whirl-pooling

The aim of whirl-pooling is to encourage precipitation of protein polyphenol complexes (cold break), to settle out hop debris and to coagulate denatured proteins (hot break) (Virkajarvi, 2001; Willaert, 2007; Herholdt, 2010). The micro-brewing apparatus used at DMUKZNP is designed in such a way that boiling, cooling and whirl-pooling occur inside the kettle. So whirl-pooling occurs during boiling and cooling. During boiling whirl-pooling coagulates the denatured proteins (hot-break) whereas during cooling whirl-pooling encourages the precipitation of protein polyphenol complexes that lose solubility at cooler temperatures (cold-break). This improves the flavour and clarity of the final beer product.

Wort cooling

Wort is cooled to below 10°C through the use of heat exchangers in the form of plates or pipes with water as a cooling medium (Kunze, 1999). Ideally, wort is also aerated during cooling to supply oxygen for use by yeast to grow during the initial stage of fermentation (Briggs *et al.,* 1981). Once the wort is cooled, it is transferred to the fermentor vessel.

Fermentation

Yeasts are facultative anaerobes, that is, they exhibit both the aerobic (presence of oxygen) and anaerobic (absence of oxygen) forms of metabolism (Raines, 2009). Yeast growth occurs during the first few hours of fermentation (Herholdt, 2010). This is necessary in order to ensure that there is enough yeast biomass to convert fermentable sugars to ethanol (Herholdt, 2010). During growth, yeast utilizes oxygen for the synthesis of sterols which are important structural components of yeast cell membranes. During yeast growth, amino acids are used as sole sources of nitrogen, while fermentable sugars are utilized as the main source of carbon and energy. This enables the yeast cells to propagate by “5-10” times their initial weight and number (Briggs *et al.,* 1981). However, when oxygen levels are depleted, yeast cells switch to fermentative metabolism whereby “much of the carbohydrate assimilated is degraded to ethanol and carbon dioxide” (Briggs *et al.,* 1981, pg 7).

During fermentation, yeast converts sugars to ethanol and carbon dioxide (Ingledew and Hysert, 1994; Kunze, 1999; Dave, 2004), as represented by the Gay-Lussac equation in fig.3.

$$C_6H_{12}0_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Figure 3: The Gay Lussac equation (*Kunze, 1999*).

It is important to note that these yeasts can still metabolize at temperatures higher than 20°C, but high temperatures influence yeast metabolism to produce unwanted flavours. pH is an important factor to consider during fermentation because it affects the quality of beer. During fermentation, pH decreases which is essential because precipitation of colloidal unstable protein polyphenol complexes is accelerated, beer taste is refined and foam stability is increased (Kunze, 1999).

Specific gravity is also an essential factor to monitor during fermentation. Specific gravity is a measure of the amount of solutes in solution. Two specific gravity readings are measured: the first reading or original gravity (OG) is taken before the wort is transferred to the fermentor vessel. The second reading or final gravity (FG) is taken at the end of fermentation just before the beer is transferred to storage tanks, bottles or kegs. The difference between the two readings signifies the amount of sugars converted to alcohol. The two values are also used for calculating the percentage of alcohol in beer. Since the FG reading indicates the amount of non-fermentable sugars present in the brewed beer, beer that has a high FG reading will tend to have a full body and low alcohol content, while beer that has a low FG value will have a thin body and high alcohol content.

Fermentation by-products are formed and these affect the taste, aroma and flavour of the beer (Kunze, 1999). Diacetyl, esters, and sulphur compounds are examples of by-products formed during fermentation (Kunze, 1999). Diacetyl is produced as a result of the chemical break down of alpha-acetolactate and released by yeast cells in the early stages of fermentation. However, at the end of fermentation diacetyl is re-absorbed by yeast cells and converted to butanediol (Herholdt, 2010). Since diacetyl has a low flavour threshold of 0.1ppm, exceeding this threshold gives beer an undesirable butter-scotch flavour (Herholdt, 2010). Thus it is important to reduce the high levels of diacetyl via the diacetyl rest involving maturing the beer at warm temperatures ranging between 14 and 16°C.

Esters are usually formed via the esterification of fatty acids by ethanol (Kunze, 1999). In beer, esters are also produced via a biochemical pathway as shown in fig. 4 below:

$$RCOOH + ATP + CoASH \longrightarrow RCO^{-}SCoA + AMP + PPi$$

$$RCO^{-}SCoA + R'OH \longrightarrow RCOOR' + CoASH$$

Figure 4: Biochemical pathway leading to the production of esters (*Peddie, 1990*).

Esters are essential aroma and flavour compounds in beer (Peddie, 1990; Virkajarvi, 2001). They have low flavour threshold levels ranging from 0.2ppm-20ppm (Peddie, 1990) and exceeding these thresholds results in unpleasant fruity flavours (Peddie, 1990; Kunze, 1999). Production of esters can be reduced by increasing wort aeration, lowering fermentation temperatures, and increasing fermentation pressure (Kunze, 1999). Once fermentation is complete, the yeast flocculates and starts to settle.

Maturation, Filtration and Packaging

Beer is matured in order to remove excess yeast and haze forming protein polyphenol complexes (Herholdt, 2010). During maturation, beer is stored at low temperatures (-2ºC), filtered and carbonated (Ingledew and Hysert, 1994; Virkajarvi, 2001). Storing beer at very low temperatures encourages the formation and precipitation of protein polyphenol complexes. Since precipitation of these complexes leads to the formation of chill haze, the beer is filtered (at low temperatures) in order to remove the haze (Herholdt, 2010). Furthermore, maturation aids in flavour development, and the removal of undesirable flavours (Inglewdew and Hysert, 1994). Once maturation is complete, beer is filtered at low temperatures. Filtration aids in the reduction of haze forming complexes and removal of solid particles to promote clear stable beer (Herholdt, 2010). Once filtered, beer is either pasteurized before being packaged or it is packaged in sterilized bottles and then pasteurized.

2.1.4 Brewing Concepts

As discussed above, brewing is a complex process that requires knowledge of concepts from several disciplines including microbiology, biochemistry, biology, chemistry, engineering, and physics. For instance, to understand yeast metabolism, students need to be familiar with a range of basic biochemistry, chemistry and physics concepts such as thermodynamics, substrates, kinetics, spontaneity, equilibrium, enzymes, inhibitors, coupling and energy. Thus, microbiology courses, such as the brewing course, ought to incorporate basic core concepts in order to promote students' understanding of the brewing process. Table 4 (Section 3.7) summarizes the basic brewing concepts that novice brewers ought to understand in order to be competent in brewing. Knowledge of these concepts is crucial because it enables students to understand the scientific principles involved in the brewing process. This in turn permits a more scientific approach to brewing in which brewers are able to use their prior brewing knowledge to interpret new information (understand) and to solve problems (apply) (Anderson and Schönborn, 2008) (Section 2.5).

It is important to be familiar with the different substrates used in brewing, as well as their composition and importance. For instance, since hops are added during the boiling stage to release aroma and bitterness (Ingledew and Hysert, 1994; Briggs *et al.,* 2004; Line, 2008), it is important to understand the chemistry occurring during the isomerization of alpha-acids to iso-alpha-acids (Briggs *et al.,* 2004). Also since different enzymes control mashing and fermentation stages, it is essential to know the various temperatures and pH values at which they are optimally active and denatured. Such knowledge will enable students to manipulate temperature conditions so as to predict the type of body the final beer product will have. Temperature is a controlling factor in mashing, lautering, boiling, fermentation and maturation, therefore it is vital to know the significance of temperature at each stage. For instance, in boiling, high temperatures enable browning reactions, sterilization and enzyme denaturation to occur. Such information will enable students to know the correct temperatures to use at each stage and to predict any consequences of using incorrect temperatures. Furthermore they should realize that brewing concepts in table 4 are interdependent. For example, enzyme activity depends on temperature, time and pH while sterility, isomerization, precipitation, solubility, and caramelization depend on temperature. Thus knowledge of all these concepts is clearly necessary for a deep understanding of the brewing process.

From the above discussion it is clear that there is a lot of theoretical information that students ought to know in order to understand the brewing process. Therefore, are lectures alone sufficient to enhance students' conceptual understanding of the brewing process? Or is it necessary to integrate brewing practicals with theory in the brewing course in order to develop deeper understanding of the brewing process? This question is addressed in section 2.2 below.

2.2 The laboratory context and its importance for learning

Laboratory work has particular significance in the learning of science, hence it has gained a lot of attention over the past years (e.g. Högström *et al.,* 2009). Furthermore, laboratory work is integrated within courses in order to put emphasis on the course content and to develop students' understanding of scientific knowledge. Laboratory work is essential for developing students' cognitive, analysing, communicative and interpersonal skills (Van-Melle and Tomalty, 2000; Taras, 2003; Hofstein and Mamlok-Naaman, 2007). In addition, laboratory work improves students' understanding of difficult scientific concepts (Al-Naqbi and Tairab, 2005; Högström *et al.,* 2009; Maldarelli *et al.,* 2009), assists students to understand how science is connected to everyday life (Millar, 2004; Hofstein and Mamlok-Naaman, 2007), and promotes active and cooperative learning (Taras, 2003; Lunetta *et al.,* 2007; Marshall, 2008). There are, however, researchers that argue that practical work is time consuming because students often attend practicals unprepared (Carnduff and Reid, 2003). Moreover, Hodson (1990) suggested that practical work can be unproductive and confusing because it is often done without "clearly thought-out purpose".

Currently, most Universities and Colleges have integrated laboratory work within courses. The reason being most educators realize that laboratory work aids students to understand difficult science concepts. For instance, educators at Arizona State University developed a laboratory exercise in which students analyzed *Drosophila melanogaster* mutants that showed some extensions of Mendelian inheritance. Results revealed improvement in students' understanding in this area (Marshall, 2008). In another example, Waechter-Brulla and Woller (2000), educators at Wisconsin University, initiated the use of a micro- brewery apparatus in beer brewing practicals in order to introduce students to industrial microbiology and develop students' understanding of the brewing process. Since then, their students' performance in fermentation microbiology has improved significantly. Brewing training institutes such as the South African Brewing Training Institute (SABTI) also make use of micro-brewery apparata to enable trainees to make beer recipes, understand malt, hop and yeast calculations and to get exposed to the brewing process and process engineering of pumps and valves (Herholdt, 2009).

In the present study I was interested in studying to what extent hands-on practical experience with the micro-brewery apparatus would enhance students' development of deeper conceptual understanding of the basic concepts of the brewing process. At DMUKZNP the aim of the brewing practical developed for the Microbiology Honours course is to introduce students to i) industrial microbiology, ii) microbial growth and metabolism, iii) limitation of microbial growth by sterilization and sanitation and iv) basic concepts essential for understanding the brewing process. Whereas in previous years the brewing practical had been done using small buckets, in 2003 the South African Breweries (SAB) donated twenty thousand Rands to the microbiology department to construct the microbrewery apparatus. The use of the microbrewery apparatus in practicals was intended to expose students to industrial brewing and develop their conceptual understanding of the brewing process. However, no research has been conducted to investigate the efficacy of using the micro-brewery apparatus in developing students' brewing knowledge. Thus the goal of this project was to explore the effectiveness of the micro-brewery apparatus as a teaching and learning tool for promoting students' understanding of the scientific concepts of relevance to the brewing process. Since the micro-brewery apparatus is a model of large industrial equipment, it was appropriate in the next section to also consider the literature regarding the role of models as teaching and learning tools.

2.3 The usefulness of models as teaching and learning tools

ERs are physical or molecular models, pictorial, diagrammatic, graphical or symbolic representations of scientific phenomena in the external world (Lohse *et al.,* 1991; Schönborn and Anderson, 2006). Internal representations, on the other hand are, cognitive models of scientific concepts constructed through mental processes (Zhang and Norman, 1994; Schönborn and Anderson, 2006; Schönborn and Anderson, 2009). Numerous studies in science education have established that ERs are essential for knowledge construction (Peña and Quílez, 2001; Treagust *et al.,* 2002) thus promoting conceptual understanding and visualization of abstract phenomena (Kozma, 2000; Schönborn and Anderson, 2009). For instance, before the 18th century, chemists had difficulties understanding pneumatic chemistry because they were not able to make a distinction between invisible gases (Kozma, 2000). However the invention of the pneumatic trough, eudiometer and gasometer enabled chemists to visualize invisible gases and measure and isolate them (Kozma, 2000). Furthermore, ERs enable students to reason analogically (Orgill and Bodner, 2007), locally and systemically (Schönborn and Anderson, 2006).

Models are a type of ER extensively used in science teaching and learning (Osborne and Gilbert, 1980; Coll *et al.,* 2005; Eichinger, 2005). Models have a target, that is, the object or process they are portraying and a source, that is the object or idea that triggered the making of the model (Hardwicke, 1995; Gilbert and Boulter, 1998). For instance, in the present study the micro-brewery apparatus is a model representing the brewing process (source) and the idea is based on the larger industrial brewing process employed in breweries (target). Models are used to improve learning (Chittleborough *et al.,* 2005), explain concepts, processes and "difficult non- observable" abstract phenomena, (Treagust *et al.,* 2002). For example, the South African brewing training institute (SABTI) makes use of a micro-brewing apparatus to demonstrate the brewing process to non-brewing trainees, to assist them to understand the brewing process, malt, hop and yeast calculations, and to expose them to the process engineering of pumps, valves and field instrumentation (Herholdt, 2009). Similarly, Universities such as the University of Limpopo[3] and the University of Wisconsin (UOW) use a micro-brewery apparatus as a teaching aid (Waechter-Brulla and Woller, 2000).

In order for models to be effective, learners ought to be able to relate the model to the target (Chittleborough *et al.,* 2005). Likewise, the strengths and limitations of the models must be made known to the students (Schönborn and Anderson, 2006). Moreover,

[3] Poster presentation at the intervarsity brewing competition held in Pretoria from the 14th – 16th August, 2009

when representing abstract phenomena, it is essential to use appropriate models because unsuitable models tend to induce learning difficulties (Orgil and Bodner, 2004).

Given the above arguments, ERs, such as the micro-brewery apparatus are crucial for the teaching and learning of the brewing process, something which I aimed to investigate in the present study. However, under what conditions are ERs effective and what influences such effectiveness? Interpretation of ERs by students is to some extent influenced by teachers and researchers. Students often fail to effectively interpret ERs because teachers tend to use them without first describing their strengths and limitations (Schönborn and Anderson, 2006). This is because experts assume that novices will automatically understand and correctly interpret ERs (Treagust *et al.,* 2002).

2.4 Learning theories, processes and models framing this study

2.4.1 Constructivism

In the present project, in order to study the development of student understanding, it was important to be familiar with the current research knowledge on how learning is thought to occur i.e. the process of learning. Constructivists describe learning as an active process enabling students to make sense of new information (Pines and West, 1986; Driver, 1989; Treagust *et al.,* 2002), and as an interaction between prior student knowledge and new scientific theories (Pines and West, 1986). Prior knowledge is considered important for achieving student learning outcomes as it may positively or negatively impact on the learning of new concepts (Von Aufschnaiter and Von Aufschnaiter, 2007). For instance, learners introduced to new scientific concepts either assimilate or accommodate the concepts (Hewson *et al.,* 1998) based on what knowledge they already have. For assimilation to occur, students ought to be dissatisfied with prior knowledge, while the new concept has to be in accordance with student experiences to assist students in problem solving (Driver, 1989). In contrast, new concepts may contradict informal student knowledge, thus students may accommodate the new concept without changing prior knowledge (Harrison *et al.,* 1999). So, how does learning occur?

2.4.2 Theories from cognitive science

Cognitive science research has generated three theories to explore the aforementioned question. These theories are the dual coding theory, the limited capacity theory, and the active learning theory (Clark and Mayer, 2008). The dual coding theory suggests that the processing of verbal and pictorial representations occurs in different and separate information processing systems. Verbal representations are processed in the verbal channel, whereas pictures are processed in the visual or pictorial channel. The limited capacity theory suggests each information channel can process a limited amount of information (Chandler and Sweller, 1991; Baddeley, 1992; Clark and Mayer, 2008), before the problem of cognitive load arises. In the present research project it was, therefore, important to ensure that the design of the brewing practical exercise was such that the microbiology honours students were not overloaded with verbal information when learning about the micro-brewery equipment and when attempting to develop sound mental models of the various components and steps in the process. This was checked as part of the goals of the project (Section 3.6).

Active learning theory suggests learning is successful if students are actively involved in learning (Treagust *et al.,* 2002), if they can depict and organize important words and illustrations into logical mental models, and integrate the mental models with conceptual knowledge (Mayer, 2001; Mayer, 2003). In the same way, Schönborn and Anderson, (2009) have pointed out that students need to have sound cognitive and visual skills in order to successfully interpret and learn from ERs such as the micro-brewery apparatus. These skills include having the ability to i) provide sound reasoning (**R-C**) using prior conceptual knowledge (**C**) of relevance to the ER, ii) "reason with the ER and its graphical features" (**R-M**) and iii) interpret, visualize and learn from the ER (**C-R-M**) (see the CRM model in fig. 7). In this regard, it was important that the interactive and hands-on nature of the brewing practical would create an active learning environment for the students. This was investigated in the present project through the collection of various observational data by the researcher (Section 3.9)

Based on the above theories, Mayer (2003) proposed the cognitive theory of multimedia learning. According to this theory, illustrated in fig. 5, graphics, pictures, animations and written text enter the cognitive system visually. Students cognitively select relevant words pictures or animations and organize these into coherent, pictorial models. Narrated words, on the other hand, enter the cognitive system audibly. Students select relevant words and organize these into coherent, verbal models. Pictorial and verbal models are then integrated with knowledge from the long term memory and the combined information is stored in the long-term memory for future use (Mayer, 2003). In my view this theory is relevant to brewing practical as students were exposed to textual, verbal and visual material. The visual experience stemming from the interaction with the model of the micro-brewing apparatus.

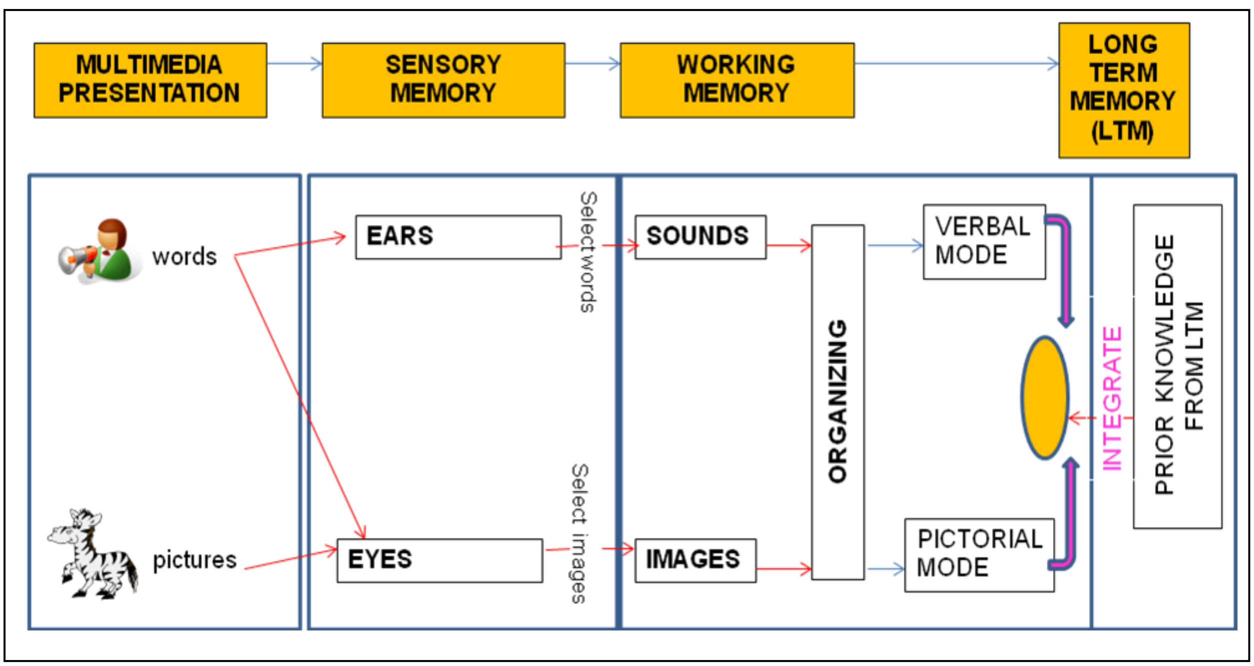


Figure 5: Cognitive theory of multimedia learning. *Adapted from Mayer, (2003).*

In 1996 Mayer developed the selecting-organizing-integrating (SOI) model to explain the learning of text without graphics. The SOI model is related to the cognitive theory of multimedia learning because it is also a construction of knowledge, based on three cognitive processes, selection, organization and integration. According to the SOI theory, shown in fig. 6 below, new information is temporarily placed in the sensory memory, selected, then transferred to the short term memory (Mayer, 1996). Conscious attention is needed to select (Mayer, 1996) relevant information from irrelevant information (Sternberg, 1985). Selected information is then organized into meaningful, coherent structures and integrated with knowledge from the long term memory as shown (fig. 6) by the arrow from the long term memory to the short term memory (Mayer, 1996). This is an important theory to help frame our thinking in the present study, since students had to work with a range of textual material in order to learn from and understand the brewing process and to perform various procedures on the equipment.

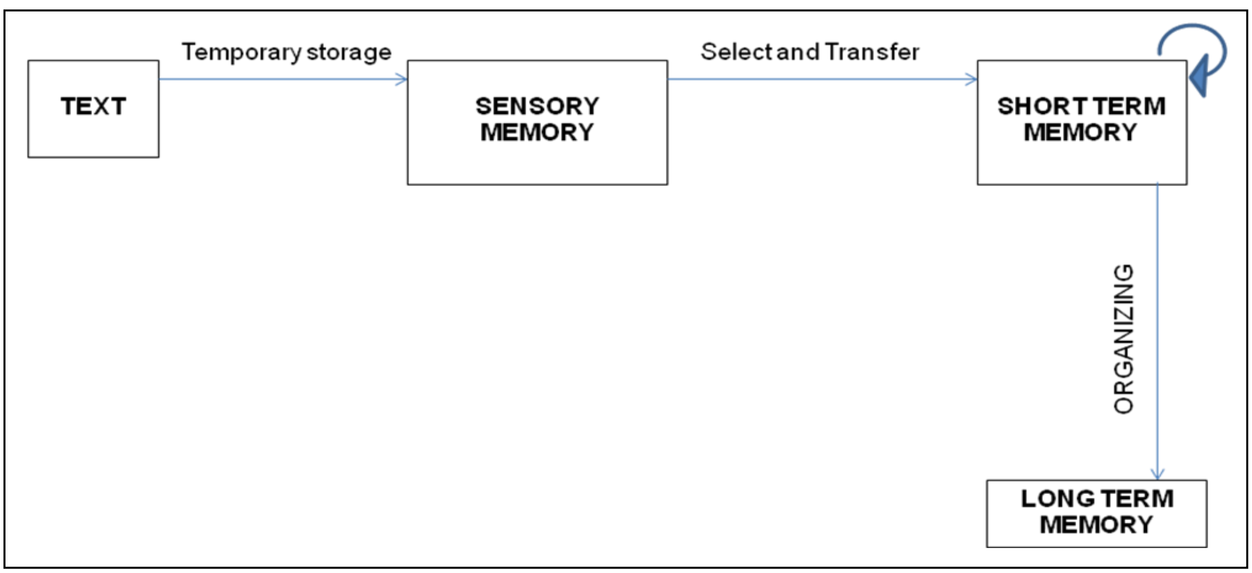


Figure 6: SOI model: a model of three cognitive processes in knowledge construction. *Adapted from Mayer (1996).*

2.4.3 The CRM Model

In 2009 Schönborn and Anderson published an empirically validated model (fig. 7) of seven factors affecting students' ability to interpret diagrams. This model has important implications for the present study as it demonstrates how cognitive and visual skills discussed in section 2.5 (also termed reasoning skills (**R**)) relate to students prior conceptual knowledge (**C**) and any representation mode (**M**) such as a diagram of the brewing process or even the brewing apparatus itself which is a model of the larger industrial equipment. Their research has revealed that the three factors, shown in fig. 7, are interdependent, that is, without prior conceptual knowledge (**C**), and the ER (**M**), students cannot utilize their reasoning skills (**R**) to make sense of the ER (**R-C**) and its graphical features (**R-M**).

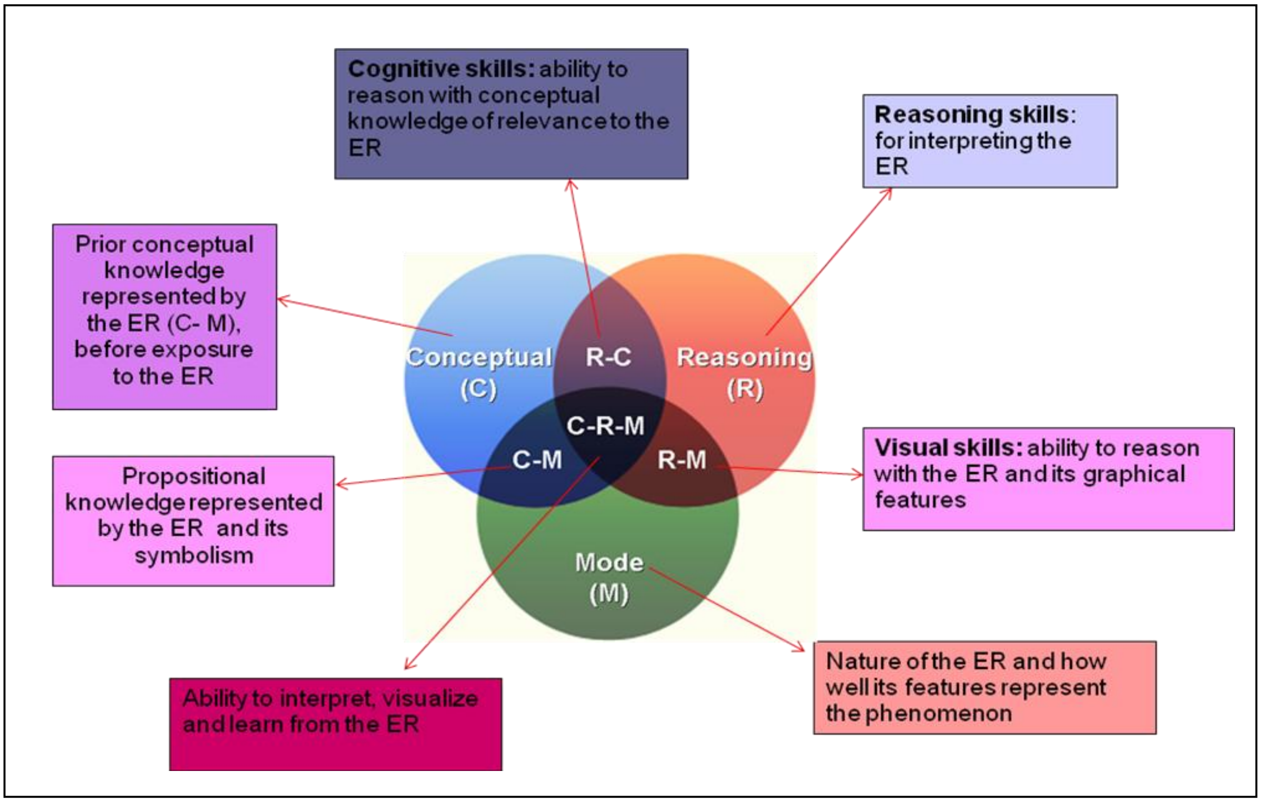


Figure 7: The CRM model showing factors that affect students' interpretation of ERs *(Schönborn and Anderson, 2009).*

Furthermore, the interpretation of ERs becomes successful if students have the skills to interpret, visualize and learn from the presented ER (**C-R-M**) (Schönborn and Anderson, 2009). Thus in the context of the micro-brewing practical, **M** represents the brewing apparatus, **C** the concepts of importance for understanding the brewing process and **R** the various cognitive, visual and technical skills that students require in order to use the equipment and to solve problems that they encounter. Thus this model provided the researcher with an important framework for the entire research process including identifying key research questions, designing the study, processing the student data and for identifying any students' conceptual and reasoning difficulties (Chapter 3 & 4).

2.4.4 Learning cycles

In the context of chemistry, some educators have indicated learning can be achieved by exposing students to the three phases of learning cycles- exploration, invention and application (James and Nelson, 1981). In the exploration phase, students are given tasks requiring exploration of new concepts and the discovery of examples related to the new concept. Thus, students are expected to develop an understanding of the new concept. For instance, in the present study, during the brewing practical, students were expected to understand the different concepts related to all the brewing stages. During the invention phase, students have opportunities to discuss, classify and characterize new concepts. During the brewing practical, students were given the opportunity to discuss the different brewing stages and their impact on the final beer product. The application phase enables students to use new concepts in different situations to solve problems, thus broadening conceptual understanding (James and Nelson, 1981). In the present study, students were expected to transfer and apply prior knowledge to solve any problems encountered during the brewing practical. Learning cycles have successfully been used in chemistry to aid students' understanding of atoms, molecules, compounds, solutions and heterogeneous matter (James and Nelson, 1981).

2.5 The meaning of conceptual understanding

Conceptual understanding is the ultimate goal of conceptual change. Conceptual understanding is multifaceted (Anderson and Schönborn, 2008) in that competence in the following cognitive skills, and many others, are required to optimize understanding. The most basic cognitive skill is mindful memorization which is the ability to memorize concepts with the intent to understand, use and apply the information to solve problems (Anderson and Schönborn, 2008). Integration on the other hand is at a much higher level of cognitive skills, measured in the present study by concept maps (see discussed below). It refers to the capability to combine memorized information into coherent cognitive structures that emphasize the relationship between concepts (Anderson and Schönborn, 2008). Analogical reasoning involving the comparison of a scientific theory with an abstract phenomenon (Orgill and Bodner, 2007); while local and system reasoning refer to the ability to use local effects to predict implications for the entire living system (Anderson and Schönborn, 2008). The development of local and systematic thinking skills are crucial because these skills enable students to be “open-minded” and to think “out of the box”. Likewise, analogical reasoning is crucial because it allows students to relate abstract phenomena to more concrete scientific concepts (Orgil and Bodner, 2007). Other cognitive skills required for conceptual understanding are related to those used in the cognitive domain of Bloom’s revised taxonomy, shown in fig. 8.

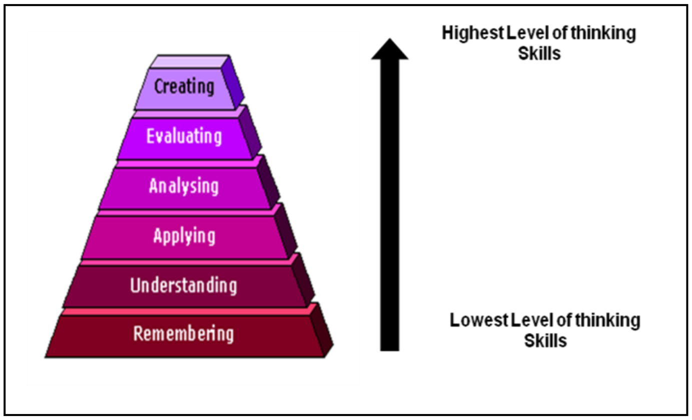


Figure 8: Revised Bloom's taxonomy showing the six levels of cognitive processes *(Anderson et al., 2001).*

Bloom's taxonomy describes the cognitive processes involved in meaningful learning. According to the taxonomy, there are six levels involved in cognitive processing: remembering, understanding, applying, analyzing, evaluating and creating (Anderson *et al.,* 2001). At the remembering level, learners are expected to retrieve information from the long term memory, and use prior relevant knowledge to recognize new information (Anderson *et al.,* 2001; Mayer, 2002). The understanding level requires learners to be able to construct meaning from new information by interpreting it based on knowledge stored in the long term memory (Anderson *et al.,* 2001; Mayer, 2002). At the applying level, learners are expected to use knowledge from the long term memory to solve new problem situations (Anderson *et al.,* 2001; Mayer, 2002). Furthermore, the analyzing stage requires learners to be able to relate new information to prior knowledge (Anderson *et al.,* 2001; Mayer, 2002). The evaluating stage requires learners to be able to use prior knowledge to criticize and make judgments of new situations (Anderson *et al.,* 2001; Mayer, 2002), whereas at the creating stage, learners are expected to put elements together to generate new functional structures (Anderson *et al.,* 2001; Mayer, 2002).

Based on the above discussion, one can deduce that competence in a wide range of cognitive skills is essential for the development of deep conceptual understanding and, where necessary, for the promotion of conceptual change, and thus it is crucial for instructors to teach such skills. This also applies to courses on brewing technology, in which instructors should be encouraged to also teach these skills to novice brewers in order to develop brewers that can not only master beer brewing but at the same time understand the fundamental concepts underpinning the brewing process. Such brewers will not only be able to troubleshoot at a technical level but will also be able to provide scientific explanations for any beer brewing problem encountered and be in a better position to solve any problems that might arise. In the present study, it was clearly important to check if the brewing TLS based on the micro-brewery apparatus developed such skills and conceptual understanding in the microbiology honours students participating in the study (Section 3.1). So how does one assess students' deep conceptual understanding in a given domain? Concept maps, amongst many other tools are considered guides to assessing students' deep conceptual understanding in a given field (Kharatmal, 2009).

Concept maps are defined as "graphical tools for organizing and representing knowledge" (Caňas *et al.,* 2004; Novak and Caňas 2006; Kharatmal and Nagarjuna 2006; Kharatmal and Nagarjuna 2009) and are excellent indicators of integrated knowledge. Concept maps have concepts arranged either as a network or hierarchy (White and Gunstone, 1992; Ruiz-Primo and Shavelson, 1996; Caňas *et. al.,* 2005; Novak and Caňas, 2006,). In a hierarchy, the most important concepts are at the top and the less important ones at the bottom (White and Gunstone, 1992; Caňas *et. al.,* 2005; Novak and Caňas, 2006,), whereas in a network, concepts are not presented in a pecking order, instead they are presented as a network (Ruiz-Primo and Shavelson, 1996). Concepts presented either as a hierarchy or network are linked by connecting lines which have linking words specifying relationships between concepts (Ruiz-Primo and Shavelson, 1996; Caňas *et. al.,* 2004; Caňas *et. al.,* 2005; Novak and Caňas, 2006; Kharatmal, 2009). Two or more concepts linked to form meaningful statements are referred to as propositions (Caňas *et. al.,* 2004; Caňas *et. al.,* 2005; Novak and Caňas, 2006; Kharatmal, 2009).

Concept maps are widely used in science education for promoting meaningful learning (Kinchin and Hay, 2000; Carnot *et. al.,* 2001; Kharatmal and Nagarjuna 2006; Kharatmal and Nagarjuna 2009), for knowledge communication (Caňas *et. al.,* 2005), and for evaluating conceptual changes occurring during cognitive development (Tsai *et. al.,* 2001; Kharatmal and Nagarjuna 2009). Moreover, studies have indicated that concept maps have also been successfully used in microbiology courses to promote students' understanding of microbiology concepts (Barenholz and Tamir, 1992; Hazel and Prosser, 1994; Kaiser, 2010). For instance Kaiser, (2010) used concept mapping in order to promote students' conceptual understanding of bacterial cell membranes and cell walls. In the present study, students were required to construct concept maps in the pre- & post tests (Section 3.8.1). This was done in order to assess any students' conceptual changes during the TLS.

2.6 The nature of conceptual and reasoning difficulties

Although educators implement various teaching and learning strategies to facilitate the development of students' understanding of scientific concepts, research shows that students still have conceptual and reasoning difficulties. Research has shown that students often hold conceptions that are scientifically incorrect, deeply rooted in their minds and hinder the learning of scientifically sound conceptions (Bulunuz *et al.,* 2008; Çelik *et al.,* 2009; Zydney, 2010). These conceptions are usually referred to as alternative conceptions, preconceptions, misconceptions (Sotos *et al.,* 2007) or simply conceptual difficulties. Studies conducted in various disciplines have indicated that students' difficulties are spread across different scientific domains. For example, in chemical engineering, it was recently discovered that students believed that the rate of heat transferred and the amount of energy transferred in a given situation were affected by similar factors (Prince *et al.,* 2009). On the other hand in biology, studies revealed learners thought the heart was responsible for "storing, cleaning, filtering and manufacturing blood," (Tekkaya 2002, cited in Aydin and Balim, 2009) while Aydin and Balim (2009) reported that grade six students believed that humans have fixed joints in their necks and waists. Although studies have been conducted in microbiology to identify students' microbiology difficulties (e.g. Alparslan *et al.,* 2003; Finlay, 2005) the author has not encountered any reported study on students' brewing difficulties. Therefore the present study was done in order to identify students' brewing difficulties and to investigate whether the use of the brewing TLS based on the micro-brewing apparatus would assist in remediating such difficulties.

Besides identifying students' difficulties, researchers have also attempted to identify teaching and learning tools that can be implemented in order to remediate students' difficulties. Various scholars have indicated that using computer simulations (e.g. Özmen *et al.,* 2009; Trundle and Bell, 2009), concept maps (e.g. Aydina and Balim, 2009), visualization tools (e.g Wu *et al.,* 2001) and conceptual change texts (e.g. Sunger *et al.,* 2001 cited in Alparslan, 2003; Özmen *et al.,* 2009) aid in promoting conceptual change and the remediation of students' misconceptions. When using either one of these methods, it is essential to ensure that instructors present scientific concepts in ways which students will find them to be intelligible, plausible and fruitful (Hewson and Thorley, 1989). In the present study, the micro-brewery apparatus (visualization tool) was used as part of a brewing TLS during the hands-on brewing practical in order to develop students' understanding of the brewing process and thus remediate their brewing misconceptions. Since remediation of misconceptions is promoted through the process of conceptual change, it was important to research the current literature in this area.

2.7 Conceptual Change theory

Chi and Roscoe (2002) describe conceptual change as "the repair of misconceptions" whereas diSessa (2002) describes it as "the reorganizing of diverse kinds of knowledge into complex systems in students' minds." To describe how conceptual change occurs, Posner (1982) and colleagues developed the conceptual change model (CCM) (Hewson and Thorley, 1989). The model has two components- status and conceptual ecology (Hewson and Thorley, 1989; Thorley and Stofflett, 1996; Hewson *et al.,* 1998). Status refers to a set of conditions that have to be satisfied in order for conceptual change to occur (Hewson *et al.,* 1998). The conditions are: intelligible, meaning the learner understands the concept and can communicate it to other learners (Hewson and Thorley, 1989); plausible, meaning the learner believes the concept is true; fruitful meaning the learner can use the concept to solve problems and make new discoveries (Hewson and Thorley, 1989); and, dissatisfaction meaning the concept contradicts prior student knowledge (Thorley and Stofflett, 1996). Therefore if the new concept is intelligible, plausible, fruitful and consistent with prior student knowledge, the possibility of conceptual change is considerably enhanced (Duit and Treagust, 2003). On the other hand, if the concept is intelligible but contradicts prior student knowledge, the concept will not be considered plausible and fruitful, and hence conceptual change may not take place (Hewson and Thorley, 1989). Circumstances under which conceptual change occurs are referred to as conceptual ecology (Hewson *et al.,* 1998). In the present study, it was clearly of great importance to create such favourable conditions, during students' use of the micro-brewery, so that the development of conceptual understanding and the remediation of any misconceptions would be promoted (Section 3.6).

Although several workers have indicated that incorporating the CCM into instructional methods aids in the promotion of conceptual change (Hewson and Thorley, 1989), other workers argue that learning takes a long time (White and Gunstone, 1989) and that students do not necessarily erase misconceptions by just being informed that their misconceptions are wrong (White and Gunstone, 1989). This led to further studies on conceptual change and strategies for promoting change. Various scholars (e.g. Suping, 2003; McCaughtry, 2005), have proposed that teachers ought to know students' naïve conceptions before instruction. This would enable teachers to create curricula that would assist in preventing or remediating students' misconceptions and thus promote conceptual change. Furthermore, researchers have advised instructors to make use of instructional methods that support active learning (Vosniadou *et al.,* 2001). Such methods include requesting students to participate in experiments and projects, solve problems, think and argue about their ideas, and listen to other students' ideas (Vosniadou *et al.,* 2001; Suping, 2003). In the present study, the brewing practical was designed in such a way that students were presented with the opportunity to engage in active learning through participating in the practical, discussing the brewing process in groups, and asking for assistance in connection with what they did not understand (Section 3.6).

Various studies have also shown that the use of conceptual change texts (Alparslan *et al.,* 2003; Özmen *et al.,* 2009) and visualization tools may also promote conceptual change (Wu *et al.,* 2001). For instance, in chemistry, the use of multimedia tools such as video clips and real time graphics enable students to visualize chemical processes at the microscopic level (Wu *et al.,* 2001) while physical models assist students to visualize atoms and molecules (Wu *et al.,* 2001). Likewise the use of computer simulations also promotes understanding and conceptual change (Trundle and Bell, 2009). For example, Akpan and Andre (2000) discovered that the use of a simulated frog dissection assisted in promoting students' understanding of anatomy, whereas Phornphisutthimas *et al.,* (2007) learnt that the use of a simulated program aided in developing students' conceptual understanding of protein purification. In the present research, the microbrewery apparatus and drawing tasks of the process were used to promote students' visualization of the brewing process, and thus aid in promoting their conceptual understanding of the brewing process.

2.8 Conclusion

Micro-brewery apparata have been used as teaching tools in various universities and brewing training institutes; however, the effect of such models as part of a teaching learning sequence on the improvement of student conceptual knowledge and understanding is unknown. Thus, in the present study, I aimed to investigate if using the micro-brewery apparatus as part of a brewing TLS would facilitate the development of conceptual understanding and visualization of essential concepts associated with the biotechnology of brewing.

Chapter 3: Methods

This chapter outlines the context of the research study and the methodological frameworks used to address the research questions of the study (see Chapter 1). There are three key contexts that directly impacted this study- the brewing-, researcher- and student contexts. In addition there is a fourth context- the science education context that strongly influences this study. It is defined by the large body of research reports and theories of learning published in the literature. This review or theoretical framework is presented in the Literature Review (Chapter 3). The present chapter also outlines the research design, including the methods used to gather and analyze data, their validity, reliability and limitations.

3.1 Brewing Context

As discussed in detail in Chapter 2 (Section 2.1.3), brewing is a process consisting of ten consecutively linked steps. Thus it is essential for novices to understand the concept of a process, particularly that the product of one step serves as a substrate for the next step, and therefore, with the exception of step one, all subsequent steps are dependent on the occurrence of the earlier steps. It is thus essential to know and understand the various complex processes occurring during each step in the brewing process. Table 2 below provides a summary of the brewing processes and the objectives of performing each step (Willaert, 2007). A more detailed coverage of the process is provided in the Literature Review, Section 2.1.3.

Table 2: An overview of the brewing process steps and their objectives. (Adapted from *Willaert, 2007)*

Brewing process stages	Action	Objective
Milling	• Grain crushing without disintegrating the husk	• Release of enzymes (alpha and beta amylases, dextrinases, glucanases, peptidases etc) • Increase of the surface area
Mashing	• Addition of specified amount of warm/hot water to the milled barley • Usage of different temperatures depending on the type and body of the beer being brewed	• Stimulation of enzyme action • Conversion of starch to glucose, maltose and dextrins • Conversion of proteins to amino-acids • Degradation of the cell wall components
Lautering	• Spraying of warm water over the mash	• Separation of the wort from the mash • Clarification of the wort
Wort boiling	• Addition of hops • Boiling of hops and wort	• Extraction and isomerization of hops • Formation of aromatic and colouring compounds (caramelization) • Formation of hot break • Sterilization of wort • Inactivation of enzymes • Removal of undesired volatile compounds • Acidification of wort • Evaporation of water
Whirl pooling	• Sedimentation or centrifugation	• Removal of spent hops • Formation of cold break • Clarification of wort
Wort cooling	• Use of heat exchangers	• Preparing the wort for the addition of yeast
Fermentation	• Addition of yeast	• Production of green beer • Obtain yeast for subsequent fermentations • Recover carbon dioxide
Maturation and conditioning	• Beer storage in oxygen-free tank	• Maturation of beer • Adjustment of the taste and CO_2 levels

	• Beer cooling	• Sedimentation of yeast and cold trub • Stabilization of beer
Packaging	• Filling of bottles, cans, casks & kegs	• Production of packaged beer

Each science domain has fundamental concepts which novices ought to understand and be able to integrate in order for meaningful learning to occur. In this case, the brewing process has various basic concepts (Section 3.7, Table 7) which learners ought to comprehend and have the ability to correctly integrate and apply (Anderson and Schönborn, 2008) so as to understand the brewing process. As a result, these concepts (Table 6) represent the theoretical aspect through which learning of the brewing process was viewed in the present study. Based on this, therefore, a key question to address in the present study was what does conceptual understanding of the brewing process entail?

For the purposes of the present study, the following meaning of conceptual understanding of the brewing process was proposed:

- Knowing the importance of each concept in brewing;
- Knowing the facts (factual knowledge) of what happens during each stage (Chapter 2, Section 2.1.3);
- Having the knowledge of how the different brewing stages interlink;
- Having the capability to explain how each stage contributes towards the final product, beer (Chapter 2, Section 2.1.3);
- Possessing the ability (cognitive skills, Section 2.5) to transfer and apply factual knowledge to explain either procedural or non-procedural brewing problems; and,
- Possessing the integration skills and knowledge to construct self-explanatory concept maps.

Furthermore, the author prepared a concept map (Appendix 7) of the various brewing concepts highlighted during the instruction of the brewing course. The map demonstrates relationships between the various brewing concepts and also served as a framework through which students' generated concept maps were analyzed (see Chapter 4).

3.2 Researcher Context

Microbiology was one of my majors at undergraduate level, however we never studied brewing as an independent course, instead it was briefly introduced during the fermentation course. As a result, at the beginning of this project, I had to attend brewing courses in order to gain more knowledge about the brewing process and develop my conceptual understanding of it. At first, I found it challenging to understand because it does not only encompass microbiology concepts but also the integration of biochemistry, chemistry, engineering and physics concepts. However, I progressively mastered understanding of these concepts and the different brewing stages, their impact on each other and on the final beer product. My rapidly evolving knowledge greatly impacted the project when it came to the collection, analysis and interpretation of data. For instance, during interpretation of results, I was able to differentiate between students who showed a good conceptual understanding of the brewing process and those who did not.

3.3 Student Context and Ethical Clearance

The study was conducted from 2009 to 2010, at the University of KwaZulu-Natal, Pietermaritzburg campus (UKZNP). Preliminary studies were carried out from February to June 2009 with eight microbiology honours students, whereas the final studies were done from March to June 2010 with ten microbiology honours students. All students were enrolled in a four-week brewing course and had previously completed (at undergraduate level) introductory physics, mathematics, chemistry and biology courses in the first year followed by the following second- and third-year courses:

- Biochemistry 201: this is a second-year module intended to provide students with an insight into molecular diversity in living systems. The module covers the hierarchy of chemical structures in prokaryotic and eukaryotic cells; the chemistry of carbohydrates, amino acids, peptides and proteins; enzymology and kinetics; the structure and function of vitamins, cofactors, and nucleic acids; and protein synthesis.

- Biochemistry 310: this module is offered at third-year level and provides students with an insight into how metabolism is manipulated and regulated in cells and whole organisms. Topics covered by this module include the integration and regulation of metabolism in animals, humans, plants and microbes under normal and stressful conditions.

- Microbiology 213: this is a second-year microbiology course aimed at equipping students with a strong foundation in the field of bacteriology. The course among many other topics covers the metabolic pathways of industrial importance; such pathways include glycolysis involved in industrial fermentation including brewing.

- Microbiology 304: this module is offered at third-year level and is intended to introduce students to the key concepts and applications in microbial bio-processing. Topics covered included the growth of microbes in controlled environments, batch and continuous bio-processing, aspects of up-streaming and down-streaming, including examples of major fermentation processes.

- Microbiology 320: this course is offered at third-year level and provides learners with a background of microbial physiology and metabolism in natural ecosystems and industrial environments. The module covers topics such as a review of microbial metabolism and energy generation under aerobic and anaerobic conditions, and metabolic regulatory systems in bacteria and biotechnology aspects of process control.

Students who completed the abovementioned modules had the basic knowledge required for understanding the brewing process, including for example enzymes and enzyme kinetics, microbial metabolism and energy generation under anaerobic conditions.

3.3.1 Ethical clearance

Ethical consent from the abovementioned students and ethical clearance to perform this study was obtained according to the specified regulations and procedures at the University of KwaZulu-Natal. In brief, student consent to participate in the study was obtained through their signing of an indemnity form (see copy in Appendix 1). Before, signing students were informed of the nature and aims of the research and given written assurance that the results of the study would not in any way affect their final marks; that the collected data would be presented in such a way that neither their names nor students numbers would be revealed, for this reason, letters A-E and G-K were assigned to the students (see Chapter 4). Furthermore, students were notified that they had the freedom to choose to stop participating at anytime if they felt uncomfortable; and that the information they provided would be kept confidential. All the necessary documentation was also submitted to the UKZN Ethics Committee for approval and ethical clearance obtained (ethical approval number HSS/1286/2010M).

3.4 Methodological Framework

Having constructed a theoretical foundation for the study, the next step was to select and consider the methodological framework that would be compatible with the discussed theoretical framework. Although a vast number of research methods exist, three types of research techniques namely qualitative, quantitative and mixed methods are commonly used in science education (Creswell, 2003). There has been great debate among researchers regarding the importance of quantitative and qualitative designs (Patton, 1990). It is however essential to state that the choice of any one of these methods is governed entirely by the nature of the conducted research and the research questions being addressed (Patton, 1990). However, one must be cautious in selecting the type of research method to use because studies have revealed that most researchers' work lacks "proper synthesis procedures" as a result of failing to choose appropriate research methods (Cooper, 1990). In the present study, it was decided that a Teaching-Learning Sequence (TLS) approach (Méheut and Psillos, 2004) would best frame the study and that the collection of qualitative data would best address the stated research questions. In this section, we give reasons for this decision and discuss the qualitative methods employed in greater detail together with an overview of the various methodologies employed in this study.

3.4.1 Choice of research paradigm

Three paradigms exist in science education research, namely post-positivist or qualitative paradigm, logical positivism or quantitative paradigm and pragmatic or mixed methods paradigm. The three paradigms differ in nature: post-positivist is subjective, logical positivism aims to be objective whereas the pragmatic paradigm is both objective and subjective (Cohen *et al.,* 2000). Furthermore, the post-positivist paradigm employs the narrative typical strategy of inquiry; logical positivism uses the experimental type of inquiry; whereas the pragmatic paradigm makes use of both the narrative and experimental types of inquiry (Cohen *et al.,* 2000). Additionally, the type of data collected in post-positivist paradigm is interpretative since open-ended questions are used, whereas the data collected in logical positivism is normative since closed-ended questions are used (Cohen *et al.,* 2000). On the other hand, the type of data collected in mixed methods paradigm is both normative and interpretative.

Of the three research paradigms, the post-positivist paradigm was employed in the current study because i) the researcher was involved as a "human instrument" in the collection of student data hence the nature of the current study was subjective; ii) data collected was narrative and interpretative because it was in the form of recorded verbal interviews, direct observations (student performance and behavior were observed during the brewing practical) and free response written documents (pre- & post tests, student generated brewing concept maps and evaluation questionnaire); iii) and data was analyzed via inductive analysis. Furthermore, the interview, pre-test and post-test questions were open-ended, enabling the researcher to gain insight into students' brewing knowledge, their brewing difficulties and the source (s) of the difficulties.

3.4.2 Motivation for a qualitative study

Phenomenological research, post-positivist or qualitative research is defined as "any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification" (Strauss and Corbin, 1990, pg. 17 cited in Hoepfl, 1997). This type of research makes use of a realistic approach so as to understand phenomena in its original settings (Hoepfl, 1997; Limbarkin and Kurdziel, 2002b; Creswell, 2003); and tests for deeper understanding and improves understanding with regards to teaching and learning (Johnson, 1995, cited in Hoepfl, 1997). Furthermore, qualitative research can be used for student evaluation (Libarkin and Kurdziel, 2002a) and to obtain "in-depth information" about phenomena. This becomes very useful especially in the current research where students were tested for their conceptual understanding of the brewing process (Section 3.8.1) and a TLS was employed in order to assist in developing students' conceptual understanding of the brewing process. Since quantitative research mainly uses closed-ended questions, which restrict participants to specific choices and preventing them from revealing their true level of understanding (Cohen *et al.,* 2000), this approach was not used in the present study. For the same reason, mixed methods were not employed in this research because they too use quantitative methods, besides qualitative methods.

Various studies reported in the literature have indicated that three main types of data are collected under qualitative research, namely i) verbal data in the form of interviews, ii) direct observations and iii) written documents (Libarkin and Kurdziel, 2002a). Likewise, in the present study, data collected was in the form of i) interviews, ii) direct student observations during the brewing practical, iii) written probes which included pre-

& posts tests, student generated concept maps and an evaluation questionnaire (Sections 3.9-3.11). In post-positivist research, the researcher acts as a “human instrument” in the collection of data and therefore it is highly possible that the researcher’s beliefs may influence the findings of the study (Libarkin and Kurdziel, 2002b). Hence the description of the researcher context in Section 3.2 above. Moreover, qualitative research uses the process of inductive analysis to analyze the collected data (Hoepfl, 1997; Libarkin and Kurdziel, 2002b). Similarly, in the current research, the researcher was directly involved in the collection of data and students’ written responses were analyzed via inductive analysis (Section 3.8.3). One important aspect to mention is that quantitative research uses big samples that represent populations and analyzes data via statistical methods. This method was not suitable for this study since a small sample of only ten students was used which would not permit any generalization of the results to other student contexts (Section 3.3). Open-ended questions are mainly used in phenomenological research and this is of great importance because participants are given the freedom to ‘say their minds’ without being constrained by specific choices of statements (Hoepfl, 1997). As a result, the researcher is able to discover the nature of participants’ true knowledge, their difficulties and the source (s) of the difficulties. For the same reasons, open-ended questions were used in the present study because it aimed to reveal students’ conceptual understanding of the brewing process, their brewing difficulties and the source (s) of such difficulties.

Validity and reliability are important in both quantitative and qualitative research. Most qualitative researchers make use of the triangulation method to increase the validity of their research methods and reliability of their research findings (Cohen *et al.,* 2000). Regarding quantitative research, validity is explained by Joppe (2000, cited in Golafshani, 2003) as the determination of “whether the research truly measures that which it was intended to measure”. Reliability on the other hand is defined by White and Gunstone (1992, pg. 182) as the degree of “consistency of the judgment that follows from the use of a test.” White and Gunstone (1992) measure reliability based on three variables, namely, the test-retest reliability (that is, would the students obtain the same scores if they re-wrote the same test?); internal reliability (that is, would the same person's performance lead to similar judgments if the test were split in half?); and reader reliability (that is, would the same scores be obtained if the test were to be assessed by various persons with similar theoretical backgrounds?). The term "validity" is commonly used in quantitative research whereas qualitative researchers prefer using terms such as "quality", "rigor" and "trustworthiness" (Stenbacka, 2001; Davies and Dodd, 2002, cited in Golafshani, 2003). However, regardless of the term (s) used, striving for validity and reliability is of great importance in any "research paradigm" (Golafshani, 2003). Similarly, since the current research involved interpreting students' verbal and written materials, striving for validity and reliability became our main goal. Nevertheless, it is important to indicate that since data is collected from humans, there are possibilities that the collected data might not be entirely replicable. This is due to the fact that students'/humans' knowledge, motivation and concentration levels change from time to time (Phelps, 1994; Cohen *et al.,* 2000).

Most qualitative researchers make use of the triangulation method (Cohen *et al.,* 2000) in order to increase validity of their research methods and reliability of their research findings. Several academics define triangulation as the employment of various methods of data collection in a study (Hyrkäs *et al,* 2003; Cohen *et al.,* 2000). Triangulation is important because it improves the validity and reliability of research results (Cohen *et al.,* 2000; Creswell, 2003) and the bias that may arise as a result of using only one method for collecting data (Cohen *et al.,* 2000; Hyrkäs *et al.,* 2003). In the present study triangulation of data was used in the research design in that various data collection methods were used to collect data about the same phenomenon (Table 3, Section 3.5). Such methods included written probes, evaluation questionnaires, observational data and interviews.

3.4.3 Teaching-Learning Sequences (TLS)

Teaching-learning sequences (TLSs) have been part of the science education research tradition since the 1980s (Méheut and Psillos, 2004). TLSs have an intervention research activity and a product (Méheut and Psillos, 2004), they include research into students' conceptions and learning perspectives (Méheut and Psillos, 2004) and they are commonly investigated at either the micro (e.g. specific session) or macro levels (e.g. single topic sequence) (Kariotoglou and Tselfes, 2000, cited in Méheut and Psillos, 2004). In the present study, the investigation was conducted at the macro-level since it was based on the topic of the brewing process (single topic sequence). Furthermore, in the current study, the TLS was used to develop students' conceptual understanding of the brewing process.

TLSs have been successfully used to develop students' understanding of science concepts. For instance, Kabapinar, and colleagues (2004) used a TLS, based on the macroscopic and quantitative aspects of solubility in terms of particles, to develop students' understanding of the concept of solubility. Moreover, Larsson and colleagues (2010) used TLS based on a physical model to develop students' understanding of viral self assembly.

Designing a TLS is not a "one shot activity"; instead, it is a long term activity that requires a researcher to consider the goals of their TLS. As a result a number of general frameworks have been designed in order to assist researchers in designing effective TLSs. These frameworks focus on a number of factors that have to be considered when designing TLSs and the processes involved (Méheut and Psillos, 2004). The developmental research framework (DRF) indicates that researchers should focus mainly on students when designing TLSs. Furthermore, this framework suggests that researchers should include motivational activities that will enable students to "build freely the ideas we want to teach them" (Méheut and Psillos, 2004). The Ingénierie Didactique framework (IDF) advises researchers to consider the following dimensions when designing TLSs: i) an epistemological dimension (ED) which takes into account the analysis of the content to be taught, the problems addressed and their historical genesis (Méheut and Psillos, 2004); ii) a psycho-cognitive dimension (PCD) which includes analyzing students' cognitive characteristics (Méheut and Psillos, 2004); and iii) a didactic dimension (DD) which involves analyzing the functioning of the teaching institution (educational constraints) (Méheut and Psillos, 2004). Although several principles are essential in informing the design of TLSs (as discussed above), principles that researchers may consider when designing their TLSs depend mainly on "personal preferences and contexts" (Méheut and Psillos, 2004). In the present study, both the DRF and the IDF informed the design of the brewing-related TLS (Section 3.5). Furthermore, the TLS approach employed in this study formed the basis of the research design that addressed the various research questions discussed in Chapter 1.

3.5 Research Design and Methodology

Table 3 shows the research design and methodology that was designed by the researcher in order to address the specific research questions stated in Chapter 1.

Table 3: TLS schedule showing the timing of the various course activities, data collection instruments and the nature of data collected to address each research question.

Date	Course activity/data collection instrument	Nature of data collected (If any)	Research question addressed *(see key below for the complete questions)
09.02. 2010	Identification of key brewing concepts	3-point (important, not important, undecided) Likert scale questionnaire. Total count of ratings per concept	1
11.03. 2010	**Brewing Lecture 1:** this was conducted by a Microbiology Masters student who is an expert brewer. The lecture was aimed at introducing the students to the brewing process. However, it covered all the essential brewing concepts shown in section 3.5.	None	-
16.03. 2010	**Brewing Lecture 2:** this was conducted by the SAB delegate. The lecture covered all the important brewing concepts and it covered every aspect of the brewing process in greater details.	None	-

17.03. 2010	**Brewing lecture 3:** this was also conducted by the SAB delegate. This lecture was aimed at introducing students to the micro-brewing apparatus and showing them how it works prior to the brewing practical.	None	-
19.03. 2010	Pre-Test	Free-response short answers	2, 3, & 4
30.03. 2010	**Brewing Practical:** this was aimed at assisting the students to construct mental models of the brewing process and thus develop their understanding of the brewing process. Students' attitude and motivational levels were observed.	Observational data	6, 8
08.04. 2010	Post-Test (identical to pre-test)	Free-response short answers	2, 3, & 4
12.04. 2010	**Group Discussion:** this involved a group tasting session and the evaluation and discussion of each group's final beer product.	None	-
7-8.06. 2010	Semi-structured interviews	Transcribed audio taped responses	2, 4 & 5
7-8.06. 2010	Evaluation Questionnaire	2-sided Likert of student evaluation of TLS	7

*1. What concepts are essential for understanding the process of beer brewing?
2. Did those students with sound conceptions develop deeper understanding during TLS?
3. Did students show any conceptual difficulties with the brewing concepts?
4. Did any remediation of such difficulties occur during the TLS?
5. Did students show retention of (mis)understanding two months after the brewing practical?
6. What were students' attitudes and motivational levels like during the brewing practical?
7. How well did students rate their experiences of the whole TLS?
8. How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding?

As shown in table 3 above, the first task dealt with identifying key brewing concepts, this task addressed research question 1. Before designing the TLS, it was important to first identify the essential brewing concepts (Section 3.7) that students ought to know in order to understand the brewing process. Moreover, knowing these concepts prior to designing the TLS was crucial because the TLS was supposed to be designed in such a way that it covered all the fundamental brewing concepts. Identification of the key brewing concepts was done with the assistance of an expert survey, as described in Section 3.7. One of the major aims of designing the TLS was to promote students' understanding of the brewing process. Therefore, since students were expected to learn or gain knowledge from the TLS, it was important to design activities that would motivate students to freely learn the brewing knowledge that would be taught during the TLS (Section 3.4 about DRF).

The TLS was based on the micro-brewery apparatus and it involved various activities (Table 3). The first TLS activity involved introducing the students to the brewing process (Brewing Lecture 1). This was done by a microbiology Masters student who was also an expert brewer. Although, only an introductory lecture, brewing lecture 1 covered all the essential brewing concepts. It is important to state that during the compilation of brewing lecture 1, its content was analyzed in order to ensure that it was entirely based on the brewing process (Section 3.4 about the IDF/ED). Following brewing lecture 1, students were exposed to brewing lecture 2: this lecture was conducted by the SAB delegate. Brewing lecture 2 also covered all the essential brewing concepts and addressed every aspect of the brewing process in greater detail. Brewing lecture 3 was also conducted by the SAB delegate and was aimed at introducing the students to the micro-brewing apparatus prior to the brewing practical. During this lecture water was run through the micro-brewery apparatus, in order to teach students how the apparatus works. Students were then divided in two groups and each group was instructed to perform the water show: this was done in order to ensure that the students had understood the operation of the apparatus. It is important to point out that during the brewing lectures; various brewing questions were posed to the students, and students were encouraged to ask questions. This was done in order to motivate and involve students in the lectures (Section 3.4, about DRF).

Following the brewing lectures, students were exposed to the pre-test. The pre-test addressed research questions 2, 3 and 4. This test was aimed at discovering students brewing conceptions after exposure to the brewing lectures (Section 3.4, about IDF/PCD). The nature of data collected from the pre- & post tests was in the form of free response short answers. The design, validation and analysis of the pre-test are discussed in sections 3.8.1-3.8.3. One and half weeks after the pre-test, students were exposed to the brewing practical. The practical addressed research questions 6 and 8, and it was intended to assist students to visualize and build mental models of the brewing process. During the practical, observational data was recorded in order to evaluate students' attitudinal and motivational levels during the TLS. Details about the design, validation and analysis of the brewing practical and observational data are discussed in sections 3.6 and 3.9.

A week after being exposed to the brewing practical, students wrote the post-test: this test was identical to the pre-test, as therefore also addressed research questions 2, 3, and 4. Design, validation and analysis of the post-test are discussed in sections 3.8.1-3.8.3. Two months after the brewing practical, semi-structured interviews were conducted: the aims of the interviews were to i) discover the source (s) of students brewing difficulties, and ii) find out whether students were able to retain their conceptual understanding and/or difficulties. The semi-structured interviews therefore addressed research questions 2, 4, and 5. Data collected from the interviews was in the form of transcribed audio taped students' responses. After being interviewed, students were asked to complete a questionnaire in which they had to evaluate the TLS which addressed research question 7. Since this was a questionnaire, the type of data collected was in the form of a two sided likert scale of students' evaluations of the TLS. The design, validation and analysis of the interviews and the questionnaire are discussed in sections 3.10 & 3.11.

3.6 Description of the Brewing Practical Activities

Students were divided into two groups (five students per group) and each group was given the choice of preparing either a lager or ale. Before brewing, each group was asked to explain i) the type of beer they were brewing, ii) the ingredients and amounts they were going to use and iii) how they were going to brew the beer (the temperature and pH profiles used, type of yeast used and the time for fermentation). During the actual brewing, students were asked various questions by the demonstrator (Appendix 8). Moreover, the students were allowed to ask the demonstrator anything they did not understand, but only after first discussing the problem (s) with group members. After brewing, the two groups decided on the days on which they would check on the brew and decrease its temperature. At the end of fermentation, which was after two weeks, the students bottled the beer, and stored it at cool temperatures for maturation. After another two weeks, maturation was complete and a group discussion was conducted in order to allow the learners to explain if the product they had was the product they had intended to brew at the beginning of the brewing process. The micro-brewing apparatus described in section 3.6.1 below, was used throughout the brewing practical.

3.6.1 Description of the micro-brewery apparatus

The micro-brewing apparatus has been used since 2003 in order to expose honours students to industrial brewing and aid them to understand the brewing process (Chapter 2, section 2.2). The fact that the brewing apparatus has been used with success by students and the University's brewing experts for more than five years validated the machine as a suitable apparatus for brewing. The brewing apparatus (Appendix 9) consists of a mash tun, a lauter tun with a spager, a kettle, a fermentor and pressure gauges. The whole micro-brewing apparatus is controlled via computer software. During brewing lecture 3 (Section 3.5), students were shown how to use the software and they were given the opportunity to utilize the software prior to the brewing practical. The latter was done in order to ensure that the students understood how to operate the apparatus using computer software. It is of great importance to state that cooling of the wort and whirl-pooling occur in the kettle. This is a major limitation and contributes to some brewing difficulties (see Chapter 4) as compared to industrial equipment which doesn't have this problem.

3.7 Selection and Validation of the Brewing Concepts

What concepts are essential for understanding the process of beer brewing?

As stated in Chapter 1 & 2, brewing is a complex process that encompasses knowledge of concepts from disciplines such as biochemistry, chemistry, engineering, microbiology and physics. Therefore, before designing the probes, it was necessary to identify and validate the basic brewing concepts that novices ought to know in order to understand the brewing process. It is crucial to state that research question 1 was addressed in this section and not under the results section (Chapter 4) because it was important to know the key brewing concepts before designing the pre- & post test instruments.

The selection of concepts was done step by step, that is, under each brewing step/stage, we considered the key concepts and parameters necessary for understanding each step. For instance, under the mashing stage, we thought an individual would first have to know the substrates used in mashing, their composition, and contribution towards the final product, beer. Furthermore, knowledge of the different enzymes involved in the conversion of starch to sugars is crucial; temperature and pH profiles necessary for enzyme activity are important; and the length/time for mashing is also fundamental in understanding the mashing process. Table 4 below shows a summary of the different brewing stages and the parameters and concepts we selected to be important for understanding each stage.

Table 4: A summary of the brewing concepts required to understand each brewing stage.

Brewing Stages	Brewing parameters/concepts
Raw Materials Stage: It is important to understand the following:	• Different raw materials involved in brewing
	• Different enzymes present in raw materials involved in brewing
	• Different microbial contamination present in raw materials involved in brewing
Mashing Stage: It is important to understand the following	• Different enzymes involved in mashing
	• Effect of pH
	• Effect of temperature
	• Effect of water quality
	• Importance of Calcium in the mashing process
Lauter stage: It is important to understand the following:	• Effect of the pH of sparging water on wort
	• Effect of oxygenation
	• Measurement of specific gravity
	• Effect of temperature
Wort boiling (kettle): It is important to understand the following:	• Effect of hop addition (time at which it is added) on wort flavour and aroma
	• Effect of pH in wort boiling
	• Effect of whirl-pooling wort
	• Effect of hot and cold breaks on wort
Fermentation: It is important to understand the following:	• Effect of temperature on fermenting wort
	• Effect of wort aeration before fermentation
	• Effect of pitching rates of yeast on fermenting wort
	• Effect of different strains of yeast on the fermenting process
	• Effect of fermentor vessel sanitation
	• Duration of fermentation
	• Glycolytic reactions (e.g. coupled reactions)

After we completed the selection, we compiled a questionnaire (Appendix 2) consisting of the above concepts. We then sent the questionnaire (for validation of the concepts) to forty master brewers from different countries, (e.g. Germany, SA, UK, and USA), and asked them to indicate concepts that were important for understanding and mastering the brewing process. Of the forty master brewers, twenty-five completed the questionnaire. Twenty of the twenty-five brewers indicated that all the concepts were very important in understanding the brewing process (Table 5 & 6). The remaining five agreed with the twenty brewers but added the concept of sanitation to the list as they considered this important in the mashing, lautering, fermentation and packaging stages (Table 6). A summary of the brewers' questionnaire results is provided in tables 5 & 6 below.

Table 5: Level of importance of brewing concepts as rated by brewing experts

Brewing concepts	Substrate			Enzymes			pH			Time			Water quality			Specific gravity			Solubility			Temperature			Sterility			Coupling			Aeration			Stoichiometry			Contamination		
Levels	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Expert brewers																																							
B1	x			x			x			x			x			x			x			x			x			x			x			x			x		
B2	x			x			x			x			x			x			x			x			x			x			x			x			x		
B3	x			x			x			x			x			x			x			x			x			x			x			x			x		
B4	x			x			x			x			x			x			x			x			x			x			x			x			x		
B5	x			x			x			x			x			x			x			x			x			x			x			x			x		
B6	x			x			x			x			x			x			x			x			x			x			x			x			x		
B7	x			x			x			x			x			x			x			x			x			x			x			x			x		
B8	x			x			x			x			x			x			x			x			x			x			x			x			x		
B9	x			x			x			x			x			x			x			x			x			x			x			x			x		
B10	x			x			x			x			x			x			x			x			x			x			x			x			x		
B11	x			x			x			x			x			x			x			x			x			x			x			x			x		
B12	x			x			x			x			x			x			x			x			x			x			x			x			x		
B13	x			x			x			x			x			x			x			x			x			x			x			x			x		
B14	x			x			x			x			x			x			x			x			x			x			x			x			x		
B15	x			x			x			x			x			x			x			x			x			x			x			x			x		
B16	x			x			x			x			x			x			x			x			x			x			x			x			x		
B17	x			x			x			x			x			x			x			x			x			x			x			x			x		
B18	x			x			x			x			x			x			x			x			x			x			x			x			x		
B19	x			x			x			x			x			x			x			x			x			x			x			x			x		
B20	x			x			x			x			x			x			x			x			x			x			x			x			x		
B21	x			x			x			x			x			x			x			x			x			x			x			x			x		
B22	x			x			x			x			x			x			x			x			x			x			x			x			x		
B23	x			x			x			x			x			x			x			x			x			x			x			x			x		
B24	x			x			x			x			x			x			x			x			x			x			x			x			x		
B25	x			x			x			x			x			x			x			x			x			x			x			x			x		
Total	**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**			**25**		

Table 6: Level of importance of brewing concepts as rated by brewing experts.

Brewing concepts	Precipitation			Caramelization			Isomerization			Process			Ingredients			Products			Other (sanitation)		
Levels	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Expert brewers																					
B1	x			x			x			x			x			x			x		
B2	x			x			x			x			x			x					
B3	x			x			x			x			x			x					
B4	x			x			x			x			x			x					
B5	x			x			x			x			x			x					
B6	x			x			x			x			x			x					
B7	x			x			x			x			x			x					
B8	x			x			x			x			x			x			x		
B9	x			x			x			x			x			x			x		
B10	x			x			x			x			x			x					
B11	x			x			x			x			x			x					
B12	x			x			x			x			x			x					
B13	x			x			x			x			x			x					
B14	x			x			x			x			x			x					
B15	x			x			x			x			x			x					
B16	x			x			x			x			x			x					
B17	x			x			x			x			x			x					
B18	x			x			x			x			x			x					
B19	x			x			x			x			x			x			x		
B20	x			x			x			x			x			x					
B21	x			x			x			x			x			x					
B22	x			x			x			x			x			x					
B23	x			x			x			x			x			x					
B24	x			x			x			x			x			x			x		
B25	x			x			x			x			x			x					
Total	**25**			**25**			**25**			**25**			**25**			**25**			**5**		

Key: 1- Important, **2**- Not important, **3-** Undecided, **B**- Brewer

One important aspect to mention is that the concept of substrates encompasses the different microscopic substances that are utilized during brewing. Such substances include glucose, proteins, starch and polyphenols. Furthermore, the concept of a process includes various processes that occur during brewing, including milling, mashing, fermentation, lautering, boiling, whirl-pooling, maturing, glycolysis and proteolysis. Using the brewers' comments, we modified our concept table (Table 4) to yield a final list of 20 concepts shown in table 7 below. These concepts were used in the rest of the study including in the design of the various probes for understanding (see 3.8 below).

Table 7: Brewing concepts

Brewing Concepts				
• substrates	• water quality	• sterility	• precipitation	• process
• enzymes	• specific gravity	• sanitation	• caramelization	• isomerization
• pH	• Solubility	• coupling	• aeration	• products
• time	• temperature	• contamination	• stoichiometry	• ingredients

3.8 Data Collection Instruments

As discussed under Research Design (Section 3.5), in order to address the research questions stated in Chapter 1, the following data-collection instruments were used in the present study: i) free-response written probes- these included the pre- & post tests, student-generated concept maps and the evaluation questionnaire, ii) observation grids for collecting data on student motivation, attitude and participation in the brewing practical, and iii) free-response clinical interviews. In the sections to follow, I discuss the processes used to design and validate these instruments. I also explain the different methods that were used to process and analyze the collected data.

3.8.1 Design of the Written Probes (Pre- & Post Tests)

Free-response questions were used in the present study because they are open-ended in nature and thus allow students to “say their minds” without being forced to think in a particular way (Grayson *et al.,* 2001; Gall *et al.,* 2003) as is the case for multiple-choice with a limited choice of options. This would facilitate students revealing their full and unique understanding. The pre- & post tests were identical, no model answers were given to the students and answers were neither discussed in lecture rooms nor during the brewing practical. The test questions (Appendix 3) were designed to i) probe students’ understanding of the brewing process and related key concepts and ii) reveal the presence of any difficulties in connection with the brewing process. Therefore, to achieve this, each test question was designed in such a way that it tested for the transfer and application of either one or more of the brewing concepts shown in table 7. A table showing test questions and concepts being probed for by each question is provided in appendix 4 while the corresponding propositional knowledge statements of sound science are presented in Appendix 5.

One of the test questions required students to construct concept maps. This was also aimed at testing students’ deeper understanding of the brewing process and their integration skills (Anderson and Schönborn, 2008). Students were provided with twenty-five concepts to draw the brewing concept maps. Instead of providing concepts such as ingredients, substrates, and processes, each concept was broken up into its constituents. For instance, instead of asking students to use the concept of ingredients in their concept maps, students were asked to use barley, hops and yeast (brewing ingredients). Furthermore, students were asked to make use of proteins and starch instead of using the concept of substrates. For this reason, students were given twenty-five concepts instead of the twenty-concepts shown in table 7.

3.8.2 Validation of the written probes

With regards to written tests, content validity is very important (Cohen *et al.,* 2000), hence the researcher had to ensure that the test i) covered all the significant brewing concepts (Table 7), ii) was relevant to the brewing process and iii) tested for students' conceptual understanding of the brewing process. To ensure that the probes were indeed testing for students' understanding of the brewing process, the model of Schönborn and Anderson, (2009) shown in fig. 7 (Section 2.4.3), and assessment guidelines as per Anderson and Rogan (2010) were used as guiding principles for designing the test probes.

According to Schönborn and Anderson (2009), conceptual understanding means the ability to memorize a concept in a mindful manner, integrate knowledge of the concept with other related concepts in order to develop sound frameworks, transfer and apply this knowledge to solve novel problems and reason analogically, locally and globally about a concept. Bearing this in mind, the researcher assessed the test probes in order to find out if they addressed the following:

Do students have sufficient prior conceptual knowledge to answer the questions?
Will the task, test and reveal evidence of both sound conceptual knowledge and any alternative conceptions in students?:
— Factor C

Will the task test and reveal evidence of students' reasoning skills and difficulties?
— Factor R

Will the task test students' cognitive skills?
Will the task reveal evidence of students' cognitive difficulties?
— Factor R-C

Does the task test students' conceptual understanding?
Does the task allow for a range of scientifically correct/creative answers?
— Factor C-R-M

Model of factors as per Schönborn and Anderson (2009)

Furthermore, the test questions were also evaluated to ensure that they addressed the following assessment guidelines provided by Anderson and Rogan (2010) (criterions written in blue above are similar to some guidelines provided by Anderson and Rogan (2010)):

- What specific concept (s) do you think your question is designed to probe?
- Will students understand the expectations and nature of the task? (i.e. do they understand the question? Is the language clear and unambiguous?)

In addition to the aforementioned, the test questions were given to six master brewers and four biochemistry experts for validation. The experts were asked to check for clarity of the questions, that is, “are the questions and language used easy to understand?” The experts confirmed that the questions and the language used were clear. Since one of the test questions required students to construct concept maps, the experts were also asked to check i) if the researcher’s concept map (Appendix 7) was clear and ii) whether relations between concepts were correct. The experts provided the following comments:

- They suggested that, instead of including the term “Brewing process” at the centre of the map, it must not be included in the map since the map was based on the brewing process.
- They pointed out that some relations (between concepts) were incorrect, for instance, they indicated that enzymes are not involved in caramelization, hence the relation between the two concepts was incorrect.
- They indicated that the map was ambiguous because most linking words were general, “too simple” and unclear. For instance words such as “important”, “has” and “are” were too general and did not distinctively convey relations between concepts.
- They suggested that where possible, scientific words or phrases should be used as linking words.

Based on the above comments, the researcher re-constructed the map (Appendix 7) using the CmapTools software (Novak, 2006). Sometimes invalidity is influenced by having either “too long or too short an interval between pre-tests and post tests,” (Cohen, *et al.,* 2000, pg. 116). Therefore to avoid this, the researcher made certain that the interval between the pre- & post tests was neither too short nor too long: the post test was written three weeks after the pre-test. In addition, the researcher was satisfied with the face validity of the probes, that is, at “face value” the test appeared to assess students’ conceptual understanding of the brewing process (Cohen *et al.,* 2000; Gall *et al.,* 2003).

3.8.3 Analysis of the Pre- & Post tests

Students’ responses were analyzed via inductive analysis in order to compress “extensive and varied raw data into a brief, summary format” (Thomas, 2003). Inductive analysis involves reading students’ responses and, without permitting preconceived ideas of what you expect to find in the data, allowing patterns of similar difficulties to emerge from analysis of the data (Schönborn, 2005). Coding is used in inductive analysis because it “organizes and makes sense of textual data” (Basit, 2003). This process includes assigning specific identification codes, to the same difficulties as and when they arise in student responses (Basit, 2003; Creswell, 2003). It is important to note that the main goal of inductive analysis is to reduce the coding categories to between three to eight summary categories. These categories are considered to be the “key aspects of the themes in the raw data” and are also viewed as important themes which address some research questions (Thomas, 2003). During inductive analysis, students’ transcripts were read a number of times in order to discover similar emerging themes, which in this case were students’ brewing difficulties. A coding frame was developed and difficulties with similar meanings were put under the same code; the coding categories were reduced from ten to three categories which represented students’ brewing difficulties.

The difficulties were then classified according to the four-level frame work (Appendix 14) proposed by Grayson *et al.,* (2001). The framework consists of four levels, namely level 1: these are new difficulties that have never been discovered by any researcher, level 2: these are difficulties that were suspected to occur by the researcher, even though their prevalence has not been investigated. Difficulties that were expected to occur and whose frequency has been studied by either one or two researchers are classified under level 3, whereas the difficulties that were also expected to occur and whose incidence has been researched and confirmed globally across multiple contexts are classified under level 4. The four-level framework also served as an instrument for measuring the reliability of the collected pre- & post tests data because the reliability of the difficulties was increased each time the difficulty was classified at a higher level. This is because in order for a difficulty to move up the levels, repeated investigations of the same difficulties should have been done by either the same researcher or other researchers. Concerning the concept maps, a deductive method consisting of a scoring system (Appendix 6) based on Novak and Gowin, (1984) and Ünlü *et al.,* (2006) was used for scoring the students' concept maps.

3.9 Description and Validation of Observational Studies

Observational studies enable the researcher to gather "live" data from "live situations" thereby giving the researcher the chance to record first instead of "second hand" data (Patton, 1990, cited in Cohen *et al.,* 2000). In the present research observational studies were employed to record first hand data regarding students' attitudinal and behavioral responses during the brewing practical. These studies were semi-structured meaning that even though observation variables (Appendix 10) were set in advance, they were measured in a less "predetermined manner" (Cohen *et al.,* 2000). Furthermore, the current researcher was involved in these studies as an observer-participant, that is, she was known to the participants as a researcher, she interacted with participants as she observed them but she did not take part in any brewing activities (Cohen *et al.,* 2000, Gall *et al.,* 2003). Since the participants knew the researcher's status, it was highly likely that they could have exerted characteristics which they thought would be favoured by the researcher causing invalidity of the data. This situation is referred to as the Hawthorne effect (Uys and Basson, 1991). However, to avoid this, the researcher secretly (without student's knowledge) rated and recorded their observations. It was also possible that the researcher's knowledge of students' performances in other activities (e.g. pre- & post tests) might have affected her judgments during observations and thus cause invalidity. To prevent this, students were requested to only write their student numbers on their test scripts, which were only processed by the researcher after the brewing practical.

As stated, attitudinal responses was one of the variables used in the collection of observational data. Attitude towards an object or activity can be expressed in three ways, namely cognitive response, affective response and behavioral response (Berg, 2005). Under cognitive response, a researcher can find out if students attempt to learn from the activity, whereas under the affective response, a researcher can investigate if students enjoy doing the activity at hand (Berg, 2005). Moreover, with regards to the behavioral response, the researcher can examine whether learners handle the laboratory equipment and prepare it for the activity at hand (Berg, 2005). Therefore, the mentioned evaluative responses were used in the current research in order to discover attitudes portrayed by students during the brewing practical (Appendix 10). Additionally, students' behavior towards an activity could be a measure of students' motivational levels. Motivation, on the other hand can be portrayed by students' commitment levels (which can be measured by students' attempt to solve problems), interest levels (which can be measured by learners' interactivity with other students and the number of questions asked and answered by the students) and participatory levels (which can be measured by either doing the activity, instructing others to do the activity or watching as others perform the activity) (Berg, 2005). Various studies have indicated that student attitudes, motivation and behavior towards laboratory activities influence the learning outcome (Berg, 2005; Winberg, 2006). For this reason, students' attitudes, motivation and behavior towards the brewing practical were observed in order to investigate their impact on students' understanding of the brewing process.

3.9.1 Analysis of the Observational Data

Observational data was collected during the brewing practical. Various criteria (Appendix 10) were used to help collect observational data. For each student, each criterion was rated based on how the student behaved/performed during the brewing practical. A scale of 1 (poor performance) to 4 (excellent performance) was used to rate students' performances and behaviors observed during the brewing practical. For instance, if during the practical student A attempted to find solutions to any brewing problem that occurred during the practical, then the student would be given a rating of 4 (excellent performance), however, if student C made no attempts to solve problems that occurred during the practical, then they would be given a rating of 1 (poor performance). Moreover, if student A attempted to answer at least seven of the ten questions asked by the demonstrator (Appendix 16), then they would be given a rating of 3 (good), whereas student C would be given a rating of two (mediocre) if they attempted to answer at least five or six questions. Furthermore, the researcher made note of any comments (related to the brewing practical) that were said by the students and any behaviors (e.g. attentiveness or boredom) expressed during the brewing practical.

3.10 Description, Validation and Analysis of the Evaluation Questionnaire

A highly structured, closed-ended evaluation questionnaire (Appendix 11) was used in this study in order to: i) allow students to evaluate the brewing practical, and ii) enable the researcher to observe and compare patterns in students' responses (Cohen *et al.,* 2000). Since the questionnaire was close-ended and structured, it had to be piloted; therefore, three microbiology Masters Students (brewers) and one biochemistry expert (Professor) were asked to critique the questionnaire. The questionnaire used (Appendix 11) was based on Winberg's (2006) questionnaire which was slightly modified in order to fit the brewing context. Furthermore, the format employed in the questionnaire was a two-sided Likert format; this type of format was used in order to decrease levels of "ambiguity" since "both sides of the scale were defined" (Berg, 2005). Validity and reliability are also very important when collecting data via questionnaires. Invalidity is sometimes increased if students take too long to return the questionnaire (Cohen *et al.,* 2000), hence to avoid this, students were asked to complete and submit the questionnaire immediately after being interviewed.

Evaluation questionnaires similar to the one used in the present study (see Appendix 11), are analyzed via the principal component analysis (PCA). However, since the sample of the present study was too small (Section 3.3), PCA was not used to analyze the questionnaire results. Instead, the learners' responses were analyzed by calculating the frequency for each type of response (Chapter 4).

3.11 Description, Validation and Analysis of the Interviews

Clinical interviews were used as one of our data collection instruments because they provided an opportunity to i) delve-deeper into students understanding of the brewing process and ii) discover the main source (s) of students' brewing difficulties. Interview questions were flexible and semi-structured in nature (Duit *et al.,* 2001; Nicoll, 2001). This was important because it allowed the interviewer to i) gather more in-depth brewing knowledge from the students (Gall *et al.,* 2003) and ii) modify questions each time patterns of interest arose from students' responses (Posner and Gertzog, 1982). Moreover, besides general questions presented to all students, the interviews also probed specific difficulties revealed by each student in the pre-/post-tests, in order to gain greater insight into such difficulties. Otherwise a standard interview protocol was followed; this included the interviewer i) introducing herself to the interviewee and explaining aims of the research and interview, ii) establishing rapport with the interviewees and iii) gaining trust from the interviewees (Gall *et al.,* 2003). Creating rapport and trust is important because in this way interviewees feel comfortable and free to say their minds, thereby enhancing the reliability of the data collection (Schönborn, 2005).

Interviews are highly prone to invalidity and unreliability. This is because in some cases, the interviewer might unintentionally ask leading questions which distort the results. Additionally, the interviewer's knowledge of participants' performances in other results might influence his/her interpretations (*halo effect*) (Cohen *et al.,* 2000). Participants, on the other hand might distort the results by saying what they think the interviewer is expecting them to say (*Hawthorne effect*). Having mentioned this, the researcher in the current study ensured, where possible, that i) the manner in which she asked questions did not lead students to the responses she was expecting, ii) she interpreted results based on interviewees' responses, rather than her own pre-conceptions, and iii) encouraged respondents to be honest in what they said and to avoid saying what they thought was expected from them.

The current research employed an interview strategy known as the 3-phase-single-interview (3P-SIT). 3P-SIT is divided into three phases, namely, phase 1, phase 2 and phase 3. Phase 1 is performed prior to exposing a learner to an ER such as a diagram, thus phase 1 investigates student's conceptual (**C** in fig. 7) knowledge prior to being exposed to the diagram (Schönborn, 2005; Schönborn *et al.,* 2007' Schönborn and Anderson, 2009). In this research, learners were asked a number of questions (Appendix 12) in order to expose their brewing conceptual knowledge prior to being exposed to the brewing diagram. Phase 2 is aimed at investigating students' reasoning (**R** in fig. 7) skills when interpreting the diagram and observing if the learners' knowledge changes after being exposed to the brewing diagram (Schönborn, 2005; Schönborn *et al.,* 2007; Schönborn and Anderson, 2009). In the current research, students were exposed to the brewing diagram and this was followed by a series of questions (Appendix 12) aimed at probing students' reasoning processes when interpreting the brewing diagram and discovering if there were any changes in students' brewing conceptual knowledge following exposure to the brewing diagram. Phase 3 allows students to assess and critically analyze the ER (Schönborn, 2005; Schönborn *et al*. 2007), this enables the interviewer to measure how far the mode (**M** in fig. 7) in which the diagram is presented affects students' interpretation of the diagram. In this research, students were asked questions (Appendix 12) which enabled them to critique the brewing diagram so that the researcher could assess the effect of the diagram on students' brewing knowledge. All interview probes were validated by one biochemistry Professor and three master brewers.

Each interview lasted for about one hour and was audiotaped and transcribed (Sumfleth and Telgenbüscher, 2001). The tapes were transcribed verbatim and included recording (in square brackets) of any motions or expressions such as pauses, signs, hesitations and giggles (Gall*et al.,* 2003).

Chapter 4: Results

Research Question 2

Did those students with sound conceptions develop deeper understanding during TLS?

Research Question 3

Did students show any conceptual difficulties with the brewing concepts?

Research Question 4

Did any remediation of such difficulties occur during the TLS?

Research Question 5

Did students show retention of (mis)understanding two months after the brewing practical?

Research Question 6

What were students' attitudes and motivational levels like during the brewing practical?

Research Question 7

How well did students rate their experiences of the whole TLS?

Research Question 8

How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding?

In this chapter I present the results collected from the pre- & post tests, brewing practical (observational data), student evaluation questionnaire and interviews during the TLS. This data is used to address each of the research questions 2-8 shown above. To facilitate a clear discussion of the results, I commence in section 4.1 with a series of summary tables of all the data collected which I use to group the students into 3 distinct categories based on their motivational levels and related overall conceptual development during the TLS. In section 4.2, I then consecutively discuss the specific conceptual development profile of each student category for each of the key brewing concepts using detailed data from a selected student to characterize the group.

4.1 Overview of Research Findings for the Ten Students

In this section, I present an overview in table format of i) students' attitude and motivation displayed during the brewing practical, ii) their evaluation responses regarding the brewing TLS, iii) the brewing difficulties generated from the pre- & post tests and iv) students' conceptual development during the TLS. This is followed by an overall conclusion which illustrates the 3 categories that students were classified under based on the attitude and motivation levels they portrayed during the brewing practical.

4.1.1 Student attitude and motivation displayed during the brewing practical

Research Question 6

What were students' attitudes and motivational levels like during the brewing practical?

As indicated in section 3.9, students' behavioral characteristics portrayed during the brewing practical were recorded. The data were analyzed (Section 3.9.1) and presented as shown in table 8.

It is evident from the results in table 8 that student B (41), D (39) and K (39) had the highest observational scores relative to a maximum score of 44. This is because during the brewing practical, these students showed a positive attitude towards the brewing TLS and their motivation levels were also high. Students' high motivational levels and positive attitudes were portrayed by the behavioural characteristics revealed by the students during the brewing practical. To be precise, student B, D and K showed high confidence and interest levels during the brewing practical and regularly asked and answered questions. The type of questions asked by these students indicated that they were interested in learning from the practical. This was demonstrated by the fact that their questions tended to be "more open-ended, imaginative, reflective and required an application of the taught brewing knowledge" (Chin and Brown, 2000). Furthermore, these students attempted to solve almost all the problems encountered during the brewing practical and were highly interactive, participative and hard working.

Table 8: Overview of students' attitude and motivation data collected as described in section 3.9

Students	Observational scores Maximum possible score = 44
A	18
B	41
C	18
D	39
E	18
G	25
H	27
I	18
J	25
K	39

As shown in table 8 above, student G (25), H (27) and J (25) obtained the second highest observational scores; lower than students B, D and K. This is because these students also appeared to be interested in the brewing practical and while their confidence levels were mediocre, they asked and answered questions, attempted to solve some problems encountered during the brewing practical and interacted with other students. Moreover, these students were participative and hard-working. To be exact, when compared to students G, H and J, students B, D and K answered and asked more questions, interacted with all the students, attempted to solve almost every problem they encountered during the brewing practical and were more hard working.

On the other hand, students A, C, E and I had the lowest observational score of 18. This is because during the practical, these students showed no interest in the practical, they did not attempt to answer or ask even a single question and they did not interact with other students. Instead of participating, the students played cards and talked about "*weekend events*".

Research has shown that motivation influences students' learning outcomes (Chin and Brown, 2000). This is because when students are interested in a particular topic, they make use of "deep cognitive and self-regulated strategies which lead to conceptual understanding" (Nolen and Haladyna, 1990). On the contrary, students not interested in a certain topic often employ surface-level strategies (e. g. memorization) which do not aid in conceptual understanding (Chin and Brown, 2000). For instance, Berg, (2005) discovered that students that showed positive attitudes and motivation during chemistry laboratory activities exhibited an improved understanding of chemistry whereas students that showed low attitude and motivational levels did not portray a developed understanding of the this topic. Furthermore, Chang and Cheng, (2008) found out that students' confidence and interest levels affected their achievements in science-related topics. To be exact, these researchers discovered that students with high confidence and interest levels showed an improved understanding of science related topics (e.g. physics, biology and chemistry) whereas those with low confidence and interest levels did not portray a developed understanding of such topics.

4.1.2 Students' Evaluation of the brewing TLS

Research Question 7

How well did students rate their experiences of the whole TLS?

Students were asked to evaluate the brewing TLS (Section 3.10) at the end of the interview. The evaluation responses were analyzed as described in section 3.10 and presented as illustrated in table 9 below.

Table 9: Overview of students' evaluation of the brewing TLS (Section 3.10 for questionnaire and Appendix 11)

Questionnaire	Students in agreement with the questionnaire statement		Students in disagreement with the questionnaire statement		Students who neither agreed nor disagreed	
	Student identity	**No. of students**	**Student names**	**No. of students**	**Student names**	**No. of students**
1. Brewing practical improved students' understanding of the brewing process.	All students	10	None	0	None	0
2. The use of the micro-brewery apparatus aided the students to visualize the brewing process.	All students	10	None	0	None	0
3. Students' confidence levels started to increase during the brewing practical	B, D, K, G, H and J	6/10	A, C, E and I	4/10	None	0
4. Students became less confused during the brewing practical	B, D, K, G, H and J	6/10	A, C, E and I	4/10	None	0
5. The brewing practical was interesting, fun and enjoyable	All	10	None	0	None	0
6. The students were interactive and attempted to solve problems encountered during the brewing practical.	B, C, D, G, H, I, J and K	8/10	A, E	2/10	None	0

The above results indicate that all ten students believed that the brewing practical assisted in developing their understanding and visualization of the brewing process.

However, the aforementioned results do not correlate with results discussed in section 4.1.4. This is because based on students' pre test, post test and interview statements, only 3 (B, D and K) students revealed an improved conceptual understanding and visualization of the brewing process. This is a common finding in the literature (e.g Rozenblit and Keil, 2002) that what students perceive in terms of their learning and understanding does not necessarily correspond to their actual improvement. Moreover, students B, D, G, H, K and J indicated that their confidence levels increased and confusion levels decreased during the brewing practical. Similarly, the researcher's observational results (Section 4.1.1) indicated that these students' confidence levels increased during the brewing practical. What is more interesting is the fact that students A, C, E and I indicated that their confidence levels did not improve during the practical. This is true because instead of actively taking part in the practical, the students played cards and talked about weekend events (Section 4.1.1).

Students B, C, D, G, H, I, J and K appear to have enjoyed the brewing practical. However, based on the researcher's observational results (Section 4.1.1), only students B, D, G, H and K showed high interest levels and enjoyed the practical whereas students C and I appeared to be bored. The fact that student C and I played cards during the practical suggests that these students were uninterested in the practical. Furthermore, students B, C, D, G, H, I, J and K demonstrated that they interacted with other students and always tried to find solutions to problems encountered during the practical. However, according to the researcher's observational results (Section 4.1.1), only students B, D, G, H, J and K were highly interactive and made an effort to solve problems encountered during the practical, whereas student C and I were not interested in the practical. Interestingly, students A and E indicated that they were not interactive and did not attempt to solve problems during the practical. This is true because, as supported by the observational results, these students did not take part in the practical; instead they played cards. Thus clearly at this stage of the study it was becoming apparent that students were falling roughly into 3 groups based on their attitude, participation and motivational levels.

4.1.3 Students' brewing difficulties

Research Question 3

Did students show any conceptual difficulties with the brewing process?

Research Question 4

Did any remediation of such difficulties occur during the TLS?

The student difficulties, identified as per the methods in section 3.8.3, were categorized as *reasoning difficulties* **(R)**, *brewing process-related difficulties* **(BP)** and *brewing parameters related difficulties* (**BPR**) with the categories being classified on the four-level framework of Grayson *et al.* (2001). Table 10 below shows a summary and description of the difficulties; the number of students with the difficulties in the pre- & post tests; questions from which the difficulties were generated; and classification of the difficulties on the four-level framework of Grayson *et al*., (2001). It must be noted that examples of quotations illustrating these difficulties and reasons for classifying each type of difficulty under the stated level of the four-level framework of Grayson *et al.,* (2001) will be provided in section 4.2. Furthermore, to minimize repetition, the observed brewing difficulties are discussed in greater details in section 4.2

Table 10: Overview of difficulties identified from student responses in the pre- & post tests.

Type of difficulty	Description of the difficulty	Students with each difficulty (10 students in total)		Probes related to the difficulties (see Appendix 3)	Classification on the four-level framework (Section 3.8.3)
		Pre-test	Post-test		
R	Ethanol will not be produced by the yeast cell if NAD^+ is present but NADH is absent	4/10 (A, B, C & D)	4/10 (A, B, C & D)	2a (ii)	Level 2
BP	During the brewing process, whirl-pooling is done in order	4/10 (B, C, H	2/10 (H & C)	3a & b	Level 1

	to cool the wort.	& K)			
BPR	The final specific gravity value is a measure of the amount of sugar converted to ethanol	2/10 (J & G)	2/10 (J & G)	6b (i)	Level 1

The above results indicate that students A, B, C and D showed the **R** difficulty in the pre- & post tests. These students believed that within the intact yeast in the presence of NAD^+, but absence of NADH, ethanol production would not occur. This suggests that the students did not understand that NAD^+ could be reduced to NADH, via the glyceraldehyde-3-phosphate dehydrogenase reaction, and that this NADH could then be used as a co-substrate in the production of ethanol; i.e. that the glyceraldehyde-3-phosphate dehydrogenase and ethanol dehydrogenase reaction are coupled (propositional statements, question 2a; Appendix 5). Therefore, this indicates that students were only reasoning locally about the alcohol dehydrogenase reaction and its essential requirement for NADH rather than thinking globally about the entire glycolysis pathway and other reactions that could convert NAD^+ to NADH. The fact that the **R** difficulty was not remediated in the post-test suggests that the students' understanding of concepts such as coupling did not improve during the TLS. In addition, students A, B, C and D did not include the concept of coupling in their pre- & post test maps, thus suggesting an inadequate understanding of this concept and how it is related to other brewing concepts (Section 4.2). Similar reasoning difficulties were identified by Anderson and Grayson (1994), Anderson *et al.,* (1999), and Grayson *et al.,* (2001) in the context of metabolism, particularly, the glycolysis pathway. These researchers discovered a localised reasoning difficulty in which biochemistry students thought that "one pair of half reactions coupled in parallel can occur without the other". It is important to state that these students showed retention of the **R** difficulty two months after the brewing course was completed (Section 4.2).

Students B, C, H and K revealed the **BP** difficulty in the pre- test. These students thought that the process of whirl-pooling was done in order to cool the wort. The students did not understand that whirl-pooling is done so as to i) encourage the occurrence of cold and hot breaks (propositional statements, question 3b, Appendix 5) and that cooling when it occurs is not done by whirl-pooling but by heat exchangers in the form of pipes and water is used as a cooling medium as described in section 2.1.3. However, in the post-test students B and K did not reveal this difficulty, thus indicating that their understanding of the whirl-pooling process improved. Students B and K retained their understanding of the whirl-pooling process even two months after the brewing course was completed (Section 4.2). Student C and H showed this difficulty in the post test, hence suggesting that the students' understanding of the whirl-pooling process did not improve throughout the TLS. Furthermore, student C and H showed retention of this difficulty two months after the completion of the brewing course (Section 4.2). The BP difficulty is a novel difficulty which has thus far not been reported in any study.

Besides the aforementioned difficulties, the **BPR** difficulty was also revealed in the pre- & post tests. This type of difficulty was portrayed by student J and G. These students thought that the final specific gravity value is a measure of the amount of sugars converted into ethanol. The learners did not comprehend that the final specific gravity value signifies the amount of non-fermentable sugars present after the completion of fermentation (propositional statements, question 6b, Appendix 5). The fact that this difficulty was revealed in the post test shows that the students' understanding of the concept of specific gravity, especially the final specific gravity, did not improve throughout the TLS. Interestingly, the students did not correctly link this concept to other brewing concepts when constructing the pre- & post tests concept map (Section 4.2), thus illustrating an inadequate understanding of this concept. Students J and G showed retention of the **BPR** difficulty two months after the brewing course was completed (Section 4.2). It must be noted that the BPR difficulty is novel and has to date not been discovered in any study.

4.1.4 Overview of students' conceptual profiles during the TLS

The brewing TLS was aimed at improving students' conceptual understanding of the brewing process and assist in remediating the observed brewing difficulties. For this reason, table 11 below shows a brief summary of students' conceptual improvement throughout the TLS. It should be noted that the nature of students' conceptual development during the TLS will be thoroughly discussed in section 4.2.

Table 11: Students' conceptual development during the TLS

Students	Test scores (%)		Concept map scores Max mark-40		Conceptual development. Yes/No	No. of difficulties portrayed	Difficulties remediated Yes/No	Retention of sound understanding. Yes/No	Retention of difficulties. Yes/ No
	Pre test	Post test	Pre test	Post test					
A	22	41	10	10	No	1 (R)	No	No	Yes
B	20	60	20	30	Yes	2 (R, BP)	Yes (BP)	Yes	Yes (R)
C	21	30	11	11	No	2 (R, BP)	No	No	Yes
D	33	65	18	28	Yes	1 (R)	No	No	Yes
E	41	49	9	10	No	-	-	No	-
G	33	48	17	17	No	1 (BPR)	No	No	Yes
H	37	43	14	15	No	1 (BP)	No	No	Yes
I	25	35	12	12	No	-	-	No	-
J	23	38	13	14	No	1 (BPR)	No	No	Yes
K	50	64	19	26	Yes	1 (BP)	Yes (BP)	Yes	No

It is clear from the above results that student A's test marks improved from 22-41%, however, this does not say anything about the nature of the student's conceptual change during the TLS. Comparison of the student's pre- & post tests revealed the learner's marks increased due to scoring higher marks in question 8 (Appendix 3). It must however be noted that when being interviewed, the student indicated that she only memorised (rote learned) the formula required for answering question 8. Furthermore, the student's conceptual understanding of the brewing process did not improve and the student showed retention of the R difficulty two months after the brewing course was completed. Furthermore, the student's concept map scores (an indicator of deeper conceptual understanding) did not improve; this is because the map contained ambiguously linked words and most propositions were either unclear or incorrect. This therefore showed that the learner's understanding of the brewing concepts and their relations did not improve during the TLS.

Student B's test marks increased from 20-60%, however, unlike student A, student B's post test marks increased because the student's understanding of the brewing process improved during the TLS. This improvement in understanding was illustrated by the post-test concept map which contained more correct propositions and more expressive scientific words as linking words than both the pre-test and that of student A (Section 4.2.1). Student B also showed retention of brewing knowledge two months after the brewing process was completed. This student did however portray the R and BP difficulties in the pre-test, but the BP difficulty was remediated and the statements made by the student in the interviews showed retention of sound knowledge. The R difficulty, however, persisted in the pre- & post tests. This therefore indicates that the learner's understanding of the glycolysis pathway did not improve during the TLS and this problem did not change two months after the course was completed.

Student C's test marks also increased from 21-30%, nevertheless, the student's conceptual understanding of the brewing process did not improve. Just in the same way as student A, student C's post test marks increased because the student rote learned a formula that was required for answering question 8 (Section 4.2.3). Furthermore, comparison of the student's pre- & post test concept maps revealed that the student's understanding of brewing concepts and their relations did not improve during the TLS. This is because the post test map had many unclear and incorrect propositions and the majority of the linking words were ambiguous. For this reasons, the student's post- test mark did not improve. Student C revealed the R and BP difficulties both in the pre- & post tests. This therefore indicates that the learner's understanding of the glycolysis pathway and the whirl-pooling process did not improve during the TLS. In addition, the student retained these difficulties two months after the completion of the brewing course (Section 4.2.3).

Student D on the other hand showed significant progress in the post test (33-65%) and comparison of the student's pre- & post tests revealed an improvement in the learner's conceptual understanding of the brewing process. As for student B, student D's improved understanding of the brewing process was also illustrated by the post-test concept map. This map showed more correct and understandable propositions, clearer linking words were used, and the map as a whole was expressive and comprehensible. For these reasons, the post-test concept map was awarded higher marks (18-28%). The student had the R difficulty both in the pre- & post tests thus indicating an inadequate understanding of glycolytic reactions. Like student C, student D also retained the R difficulty two months after the completion of the brewing course.

In the same way as students A and C, students E, G, H, I and J showed an increase in their post-test marks, however the increase did not occur because the student's conceptual understanding of the brewing process had improved, instead, the students rote learned a formula required to answer question 8 (Appendix 3). By so doing, the students obtained higher marks for this question hence their post-test marks increased. Students E and I did not reveal any brewing difficulties, whereas students G and J showed the BPR difficulty in the pre- & post tests thus indicating a poor understanding of the concept of specific gravity. What is more interesting is the fact that in their pre- & post test concept maps, the students incorrectly linked specific gravity to other brewing concepts (Section 4.2.2). Moreover, these students retained the BPR difficulty two months after the brewing course was completed. Student H on the other hand had the BP difficulty both in the pre- & post test, hence showing an inadequate understanding of the whirl-pooling process. The student also retained this difficulty two months after the brewing course was completed. Like students A and C, students E, G, H, I and J's concept maps also revealed that these students' understanding of the brewing process did not improve during the TLS. The students' pre- & post test maps were ambiguous and contained many incorrect propositions. However in certain cases, for example for students E, H & J, all twenty-five concepts were included in their post-test maps resulting in the students being awarded one point which meant their overall concept map scores increased by one point.

Student K's post test marks remarkably increased from 50 to 64% suggesting an improved understanding of the brewing process. The learner's improved understanding was confirmed by his/her improved post test concept map. Compared to the pre-test map, the post-test map was more expressive, contained clearer and sounder propositions and most of the linking words were comprehensible. Student K demonstrated the BP difficulty in the pre-test; however, this difficulty was remediated in the post-test showing a development in the learner's understanding of the whirl-pooling process. Furthermore, during the interviews the learner's statements indicated retention of the sound whirl-pooling knowledge.

It is essential to note that out of the ten students, only three (B, D & K) showed i) an improved understanding of the brewing process and ii) retention of the learnt sound knowledge. As discussed in section 4.1.1, these students also showed positive attitudes and high motivational levels during the brewing practical. This suggests that the students' good attitude and motivational level contributed positively towards the students' conceptual development. Students G, H and J also showed high commitment levels during the brewing practical. However, their brewing knowledge did not improve showing that positive attitude and high motivational levels do not guarantee conceptual development. In contrast, students A, C, E and I did not show any interest in the brewing practical (Section 4.1.1) and their understanding of the brewing process did not improve. In this case low attitudes and motivational levels probably did contribute to no increasing in learning.

4.1.5 Relationship of Performance in Brewing Process to Students' other Microbiology Courses

Student performance in the brewing course was compared to their performances in other microbiology courses to establish whether there was any correlation across these courses. The results obtained are presented in table 12 below.

Table 12: A comparison of students' performance in the Research Techniques, Applied Microbiology and Brewing courses

Students	Marks obtained (%)			
	Other microbiology courses		Brewing course	
	Research Technique Course	Applied Environmental Microbiology	Pre-test	Post-test
A	58	64	22	41
B	65	68	20	60
C	54	58	21	30
D	64	55	33	65
E	62	64	41	49
G	63	61	33	48
H	60	58	37	43
I	56	67	25	35
J	64	60	23	38
K	63	72	50	64

It is evident from the above results in table 12 that students B, D & K performed well in all the mentioned courses. This supports the idea that highly motivated students are likely to show good achievements in most of their courses. This idea did not however apply to students A, E, G, H, I & J who performed well in the microbiology courses, but poorly in the brewing course. However, there was a strong correlation between student C's performance regarding the above courses and the brewing practical- both being very poor. Thus as in the case of the other data collected in this study, motivation appears to be important for performance but motivation alone will not guarantee good performance.

4.1.6 Conclusion

Based on the above overview of results it was decided to group the students into three categories based on their similarities with respect to their conceptual development (or lack thereof) relative to their motivation and attitudes during the brewing practical. The groups decided on where as follows: i) students that were highly motivated during the TLS and thus portrayed an improved conceptual understanding of the brewing process (*students B, D & K*); ii) students that were motivated during the TLS but did not reveal an enhanced understanding of the brewing process (*students G, H & J*) and iii) students that were demotivated during the TLS and therefore did not show a developed understanding of the brewing process (*students A, C, E & I*).

Although the students' brewing course scores gave useful information about students' overall performance and motivation (Section 4.1.5), in order to gain deeper insight into the actual nature of the students' conceptual development, it was necessary to examine their various qualitative responses. Therefore, in the next 3 sections each group is discussed further and detailed data is presented for a representative student within each category in support of the above findings and to illustrate the nature of conceptual change.

4.2 The nature of students' conceptual change during the TLS

Addressing Research Questions 2-8

As stated in Chapter 1, the aim of this study was to track any change in Microbiology honours students' conceptual development during a brewing TLS. To achieve this and address research questions 2-8, we found it important to i) track the conceptual development/change (if any) of each student throughout the TLS; ii) point out if each student's attitude and motivational levels during the TLS correlated with their overall performances and iii) track one student's performance from each group as representative of the group, to avoid extensive repetition of explanations of similar data.

4.2.1 Students that showed interest in the brewing practical and thus portrayed improved conceptual understanding of the brewing process (Students B, D & K)

As outlined in section 4.1.2, students B, D & K's evaluation responses indicated that they gained extensive knowledge from the brewing TLS and their confidence levels improved during the brewing practical. Additionally, all three students pointed out that the brewing TLS was interesting and that they made an effort to learn from the practical and interact with the equipment and other students. The students' evaluation responses also correlated with the researcher's observational results which indicated that the students were committed, interactive, participative and hard-working during the practical. Moreover, as shown in subsequent sub-sections, the students' high attitudinal and motivation levels and evaluation of the TLS correlated with their outstanding performance throughout the TLS, suggesting that the TLS worked very positively for these students.

Since the students' profiles were highly similar, student B's profile will be discussed in great details, together with selected quotations, in order to track the student's conceptual development during the TLS. However, prior to this, the students' conceptual status throughout the TLS, with respect to each of the 20 concepts identified in section 3.7, was summarized as presented in table 13 below.

Table 13: The Conceptual Status of students B, D & K

Brewing Concept	Overall Pre-Test (Sound/Difficulty)*	Overall Post-Test (Developed/ No change)*	Pre-Test Concept Map (Sound/Unsound links)		Post-Test Concept Map (More sophisticated/unsound links corrected)			Conceptual Development during TLS? Yes/No	Remediation of any Difficulties Yes/No		Retention of understanding after 2 months Yes/No
STUDENT B			Ambiguous map. Overall score=20		Coherent & expressive map. Overall score=30				**R**	**NR**	
			No.SL	**No.USL**	**No.MSL**	**No. SL**	**No.USLC**				
Substrate	S	S	1	0	2	3	0	CD	-	-	Y
Enzymes	S	S	3	0	0	4	0	CD	-	-	Y
pH	S	S	0	0	0	0	0	NC	-	-	Y
Temperature	S	S	1	1	0	0	0	CD	-	-	Y
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Sterility	S	S	0	0	0	1	0	CD	-	-	Y
Water quality	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Process	S	S	5	1	5	7	1	CD	-	-	Y
Specific gravity	NE	S	0	0	0	1	0	CD	-	-	Y
Solubility	D	S	NE	NE	NE	NE	NE	CD	R	-	Y
Stoichiometry	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	S	S	0	0	0	0	0	CD	-	-	Y
Isomerization	S	S	0	1	0	1	1	CD	-	-	Y
Contamination	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Precipitation	D	S	NE	NE	NE	NE	NE	CD	R	-	Y
Caramelization	NE	S	0	0	0	1	0	CD	-	-	Y
Ingredients	S	S	2	1	2	1	1	CD	-	-	Y
Products	S	S	3	0	2	2	0	CD	-	-	Y

STUDENT D			Ambiguous map. Overall Score = 18		Coherent & expressive map. Overall Score = 28						
Substrate	S	S	2	0	1	3	0	CD	-	-	Y
Enzymes	S	S	4	0	1	3	0	CD	-	-	Y
pH	S	S	1	0	0	2	0	NC	-	-	Y
Temperature	S	S	3	0	0	4	0	CD	-	-	Y
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	D	D	0	1	0	0	1	NC	-	NR	N
Sterility	S	S	0	0	0	1	0	CD	-	-	Y
Water quality	S	S	NE	NE	NE	NE	NE	NC	-	-	Y
Process	S	S	2	0	2	4	0	CD	-	-	Y
Specific gravity	S	S	1	0	0	1	0	CD	-	-	Y
Solubility	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Stoichiometry	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	Y
Aeration	S	S	0	0	0	1	0	CD	-	-	Y
Isomerization	S	S	1	0	0	1	0	CD	-	-	Y
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Caramelization	S	S	1	0	0	1	0	CD	-	-	Y
Ingredients	S	S	1	0	0	2	0	CD	-	-	Y
Products	S	S	1	0	0	1	0	CD	-	-	Y
STUDENT K			Ambiguous map. Overall score=19		Coherent & expressive map. Overall score=26						
Substrate	S	S	2	0	0	3	0	CD	-	-	Y
Enzymes	S	S	3	0	1	3	0	CD	-	-	Y
pH	S	S	2	0	0	2	0	CD	-	-	Y
Temperature	S	S	3	0	0	3	0	CD	-	-	Y
Time	S	S	NE	NE	NE	NE	NE	NC	-	-	Y
Coupling	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Sterility	S	S	1	0	0	1	0	CD	-	-	Y
Water quality	S	S	NE	NE	NE			CD	-	-	Y
Process	S	S	3	0	1	3	0	CD	-	-	Y
Specific	S	S	1	1	0	1	0	CD	-	-	Y

gravity											
Solubility	D	S	NE	NE	NE	NE	NE	CD	R	-	Y
Stoichiometry	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Sanitation	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Aeration	S	S	1	0	1	1	1	CD	-	-	Y
Isomerization	S	S	0	0	0	1	0	CD	-	-	Y
Contamination	S	S	NE	NE	NE	NE	NE	CD	-	-	Y
Precipitation	D	S	NE	NE	NE	NE	NE	CD	R	-	Y
Caramelization	NE	S	1	0	0	1	0	CD	-	-	Y
Ingredients	S	S	2	0	0	3	0	CD	-	-	Y
Products	S	S	2	0	0	2	0	CD	-	-	Y

***Key: S-** sound, **D-** difficulty, **NC-** no change, **SL**- sound link, **USL-** unsound link, **R-** remediation, **NR-** no remediation, **MSL-** more sophisticated links, **USLC-** unsound links corrected, **CD-** conceptual development, **NC**- no conceptual development, **NE**- not established

Table 13 summarizes students' conceptual development during the TLS. Clearly overall, students' conceptual knowledge improved. Perhaps more interestingly though is the fact that after two months, these students still showed good understanding of the brewing concepts. The fact that these students retained their knowledge constitutes strong evidence that they had acquired deep understanding of most of the concepts of relevance to the brewing process during the TLS. Notice though that although they all had a sound understanding of most brewing concepts, students B and D's understanding of the concept of coupling did not improve, although in the case of student B this problem was not established (NE) via his/her concept map. *NE* means that the student did not portray whether they did or didn't understand the concept because they did not provide any answer for the question that probed their understanding of that concept.

All the three students' concept maps developed from being very ambiguous to being more coherent and expressive during the TLS. This was illustrated by their post-test maps being more sophisticated and having sounder links with more appropriate scientific brewing language as linking words. This suggested a deeper understanding and a more integrated knowledge of these concepts and their relationship to other brewing concepts. Moreover, most of the students' unsound links used in the pre-test maps were corrected in the post-test. For instance, in the pre-test, student D had an incorrect link from the concept of temperature; however, this was corrected in the post test. In some cases though the students did not include certain concepts in their maps (NE) suggesting that they may have not understood those concepts and their relationships to other brewing concepts. For instance, in the post-test, student B did not have any links to the concept of sterility, which changed to one link in the post-test. In the next section student B's profile is discussed in greater detail as a representative example of this group and illustrated with specific quotations.

Student B's conceptual change profile during the TLS

Student B experienced the **R** difficulty (Section 4.1.3, Table 10) in the pre- & post tests, suggesting that the student did not understand the concepts of glycolysis and coupling. Below are quotations provided by the student in the pre- & post tests;

Pre-test response	Post-test response
***Qu. 2a:** "[..] If NAD^+ was only present, ethanol would not be produced because alcohol dehydrogenase uses the free hydrogen ions from NADH."(**R**)	**Qu. 2a:** "[..] At the alcohol dehydrogenase step, the process would stop because the enzyme needs H+ ions to function. Therefore, the final result is that no ethanol will be produced." (**R**)

***Qu.**- question in Appendix 3

In the above quotes, the student is correct in saying that the activity of alcohol dehydrogenase is dependent on H^+ being supplied by NADH as part of the mechanism of the reaction, However, the difficulty lies in the student's lack of understanding that within the intact functional yeast cell, the NAD^+ will be converted to NADH, by the glyceraldehyde-3-phosphate dehydrogenase reaction, which will then become available for the alcohol dehydrogenase reaction. This suggests that the student was only reasoning locally about the reaction and not thinking globally about the metabolism with the whole cell and the fact that NADH might be supplied via another reaction in glycolysis since the two reactions are coupled. In a similar way, various researchers (e.g. Anderson, and Grayson, 1994; Grayson *et al.,* 2001) discovered that students had localized reasoning difficulties with metabolism, specifically, the glycolysis pathway. The fact that the R difficulty persisted in the post-test constitutes evidence that some difficulties are resistant to change and may hinder subsequent learning (Bulunuz *et al.,* 2008; Zydney, 2010).

Since the **R** difficulty was experienced in the post-test, interviews were conducted in order to locate the possible source (s) of the difficulty. In the interview, the student provided the following statements:

> ***Interviewer (I):*** "explain why you think ethanol will not be produced in the presence of NAD^{+}"
>
> ***Student (S):***
> "If NAD^{+} is present, then this reaction will continue, [points to the reaction involving the production of 1,3 bisphosphoglycerate from glyceraldehyde-3-phosphate], ethanol will not be produced because you see [points to the last reaction in which acetaldehyde is converted to ethanol], this reaction needs NADH, so there is no NADH because this NADH [points to the NADH formed from the reduction of NAD^{+}] is lost and not used in the reaction"

The above statement gives greater clarity to the nature of the R difficulty. Clearly the student is able to think globally about the other reactions in the glycolytic pathway but does not understand that the two reactions are coupled in parallel in that the NADH produced from the NAD^{+} in the glyceraldehyde-3-phosphate dehydrogenase reaction is readily available for use by the alcohol dehydrogenase reaction. It is common for students to be misled by the spatial arrangements of metabolic pathway diagram and think that a reaction occurring much earlier or later in a pathway would be 'too far removed' to be coupled to it or to be able to supply intermediates to it (Anderson, pers. Comm.). This might have been the source of the problem in this case but would require further research (propositional statements, question 2a, Appendix 5). The **R** difficulty was therefore classified at level 2 of the four-level framework (Grayson *et al.,* 2001).

Student B also showed the **BP** difficulty in the pre-test; thereby suggesting a possible poor understanding of the purpose of whirl-pooling and therefore possibly of the concepts of solubility and precipitation. However, this difficulty was not portrayed in the post-test, suggesting that remediation had occurred during the TLS. The following quotations were illustrated by student B in the pre- & post tests:

Pre-test response	Post-test response
***Qu. 3:** "Whirl-pooling allows for the decrease of wort temperature [….]."(**BP**)	**Qu. 3:** "The whirl-pool is done to remove all coagulated proteins produced during boiling and remove hop residues from wort. Therefore if whirl-pooling is not done, [….] the final beer will have debris from hops and it will be an unclean beer with a bitter or sour taste. And if the coagulated proteins were not removed, the beer will be hazy because of the protein polyphenols complexes which will have precipitated if the wort had been whirl-pooled"

***Qu. -** question I Appendix 3

It is clear from the pre-test quote that the learner's understanding of the whirl-pooling process was limited; hence they thought whirl-pooling cooled the wort. However, the post-test quotation indicates an improved understanding of the whirl-pooling process. This is because, i) the student correctly stated the purpose of the whirl-pooling process, which is to remove and sediment debris such as coagulated proteins and hop residues in order to prevent the formation of beer haze (propositional statements, question 3, Appendix 5). What is more interesting is the fact that the learner was able to apply her factual knowledge (*whirl-pooling sediments coagulated proteins and hop residues*) in order to indicate the effects of unwhirl-pooled wort on the final product, beer (*hazy bitter beer due to the presence of protein polyphenol complexes*). True conceptual understanding stems from having the ability to memorize information in a mindful manner, transfer and apply the information to solve and explain situations (Anderson & Schönborn, 2008). The student's improved conceptual understanding of the whirl-pooling process during the TLS was further verified during the interviews which were conducted two months after the TLS. The following quotation was provided by student B during the interviews:

> **I:** “What is the significance of whirl-pooling in brewing?”
>
> **S:** “You see, when whirl-pooling occurs, the thing, ummh [thinks for a while] yah, the hop debris and all the coagulated proteins settle at the bottom in a cone shape [the student forms a cone with her hands and then indicates that during whirl-pooling, the debris settles at the bottom in a cone shape] and this is important because it clears the wort so that the beer will not have haze. [..] you see, haze forms when proteins form complexes with polyphenols and during whirl-pooling, the complexes precipitate.”

It was encouraging to discover that even though two months had passed since the student studied the brewing course, the learner still remembered the whirl-pooling process, and could still transfer and apply their factual knowledge to explain the significance of whirl-pooling in brewing. Moreover, as the student was talking, the researcher could see that the learner had a visual picture of what they were explaining because in some instances (as shown in the quote), the learner even used hand gestures to demonstrate how they had seen whirl-pooling occurring during the brewing practical. Based on this, therefore, it can be deduced that student B’s conceptual understanding of the whirl-pooling process greatly improved because true conceptual understanding stems from having the ability to memorize information in a mindful manner, transfer and apply the information to solve and explain situations (Anderson & Schönborn, 2008). Furthermore conceptual understanding is characterized by knowledge retention; retaining knowledge for long periods is indicative of true conceptual understanding (Mayer, 2002). As discussed earlier, the learner’s conceptual development might have also been facilitated by his/her high motivation and commitment levels during the brewing practical (Section 4.1.1).

Besides the above difficulties, student B also showed sound conceptual knowledge of the brewing process in the pre-test which improved significantly in the post-test. The following illustrations show the differences between the learner's conceptual knowledge in the pre- & post tests:

Pre-test response	**Post-test response**
***Qu. 4:** Alpha acid converted to bittering units "[….] to add bitter flavour [….]"	**Qu. 4:** Hops are added as they contribute to the flavour and aroma. [….] hops give beer a bitter taste [….] isomerization of alpha acids occurs to release the bittering units
To remove DMS [….] -volatile DMS evaporates [….]"	"DMS is volatile and has undesirable sweet corn flavour and evaporates out of the wort during wort boiling [….]"
	"Sterilization is done to kill vegetative bacteria which could be potential contaminants and could compete with the yeast during fermentation and […] would cause bad flavour and unclear beer [….]"
	"Sugars are caramelized during boiling, this influences the colour of the beer to be darker [..]"

***Qu.-** question in Appendix 3

Although in the pre-test the student managed to list a few processes that occurred during wort boiling, they were not able to explain the importance of each process in brewing. This was probably due to a limited understanding of the wort-boiling process. Conversely, in the post-test, the learner did not only provide factual knowledge in connection with the wort boiling stage, but she managed to correctly explain the significance of each wort boiling process (e.g. *isomerization, sterilization, caramelization and vaporization*) in brewing (see propositional statements, question 4, Appendix 5). For instance, student B listed *"sterilization"* as one of the wort boiling processes: the learner elaborated on what occurs during sterilization (*which is to kill vegetative bacteria*); the importance of wort sterilization (*which is to minimize/remove micro-organisms that will compete with yeast during fermentation*) in brewing; and the effect of wort sterilization on the final product, beer (*beer will have a good flavour and taste and its clarity will be* *improved*). The fact that the learner's prior sound explanations (pre-test) improved indicates a development in the student's conceptual understanding of the wort boiling processes. It must be noted that the student's improved understanding of these concepts was also witnessed in the post-test concept map in which the student correctly linked these concepts to other concepts and thus formed coherent propositions (fig. 9).

One of the reasons for conducting one-on-one interviews was to check whether student B retained the conceptual understanding portrayed in the post-test responses. When asked to explain the effects of each brewing stage on the final beer product student B provided the following answers:

> **I:** "Use the diagram provided to explain how each stage contributes to the final product."(Phase 2, probe 2a, Appendix 12)
>
> **S:** "[..] In the kettle is where you add your hops for aroma, the smell of the beer, and the isomerization of the alpha-acids takes place so as to release bittering units. Sterilization occurs here to kill any microorganisms that might affect the activity of yeast and taste of the beer, coagulation of proteins to avoid them to bind with polyphenols and form haze in beer [...], sugars are caramelized to make wort have a dark colour, and DMS which gives beer a sweet corn flavor evaporates."

It is evident from the above quotes that student B's understanding of concepts such as isomerization, caramelization, and sterilization improved during the TLS. Clearly the student used prior conceptual knowledge (**C** in fig. 7) to explain in detail, how the processes that occur during the wort-boiling stage contribute to the final beer product. The student was able to: cognitively access and select information (from the long term memory) relevant to the wort boiling stage; process the information; and provide reasonable statements explaining the affect of wort boiling on the final product, beer (**R-C** in fig. 7). Additionally, the above quotes indicate that the student retained the knowledge she gained from the TLS.

The student's understanding of specific gravity also improved during the TLS. In the pre-test, the student did not provide any response when probed about specific gravity whereas in the post test, the student was able to indicate that the final specific gravity (SG) value is a measure of the amount of non-fermentable sugars left after fermentation. The student further indicated that the final SG value affects the body of the beer in a sense that low final SG means that the beer will have a thin body and high alcohol percentage whereas a high final SG value indicates that the beer will be full bodied with a low alcohol percentage. Student B's problem-solving skills also improved. Whereas in the pre-test, the student was not able to calculate the percentage (w/w & v/v) of alcohol in beer, in the post test, this was correctly done. Furthermore, at each step of the calculation, the student explained what the calculated value symbolized and how stoichiometry influenced that value. Moreover, in the interviews, the student stated that the fact that they had to calculate the alcohol percentage of their beer helped improve their understanding of how specific gravity values (OG & FG) and stoichiometry were used to calculate alcohol percentage. This was supported by the following interview quotation:

> **I:** "Can you please explain how you managed to correctly calculate the alcohol percentage here and in the post-test?" (Phase 1, probe 1c, Appendix 12)
>
> **S:** "mhh, you see, at the end of brewing, we were told to calculate the alcohol percentage of our beer, so we discussed it in our group, and showed it to the demonstrator who explained in detail how the equations and the specific gravity values worked when calculating alcohol percentage."

Student B also revealed an improved understanding of how concepts such as temperature, and enzymes affected the various steps of the brewing process and the final product. This is evident from the following quotations:

Pre-test response	Post-test response
***Qu. 1b:** "In mashing [..] Temperature is increased to 65°C to activate the enzymes, alpha and beta amylases which convert starch to sugar […]. In boiling, boiling helps with protein denaturation, wort sterilization and foam stabilization. [..]"	**Qu. 1b:** "[..] starch grains are converted to sugars during mashing. This conversion is influenced by the different temperature profiles which activate different enzymes. At 49-55°C, proteases break down proteins to amino-acids which are useful for yeast growth. Also breaking down proteins is good because it prevents the formation of haze in beer. [..] At 65°C, beta-amylase which converts starch to fermentable sugars is activated. This affects the body of the beer and produces a beer with a thin body. At 72°C, alpha-amylase is activated and this converts starch to non fermentable sugars which affect the body of the beer because the beer will have a full body. [..] In boiling, high temperatures are used so that wort is sterilized, hops are isomerized to give bitterness and aroma, and enzymes are deactivated."

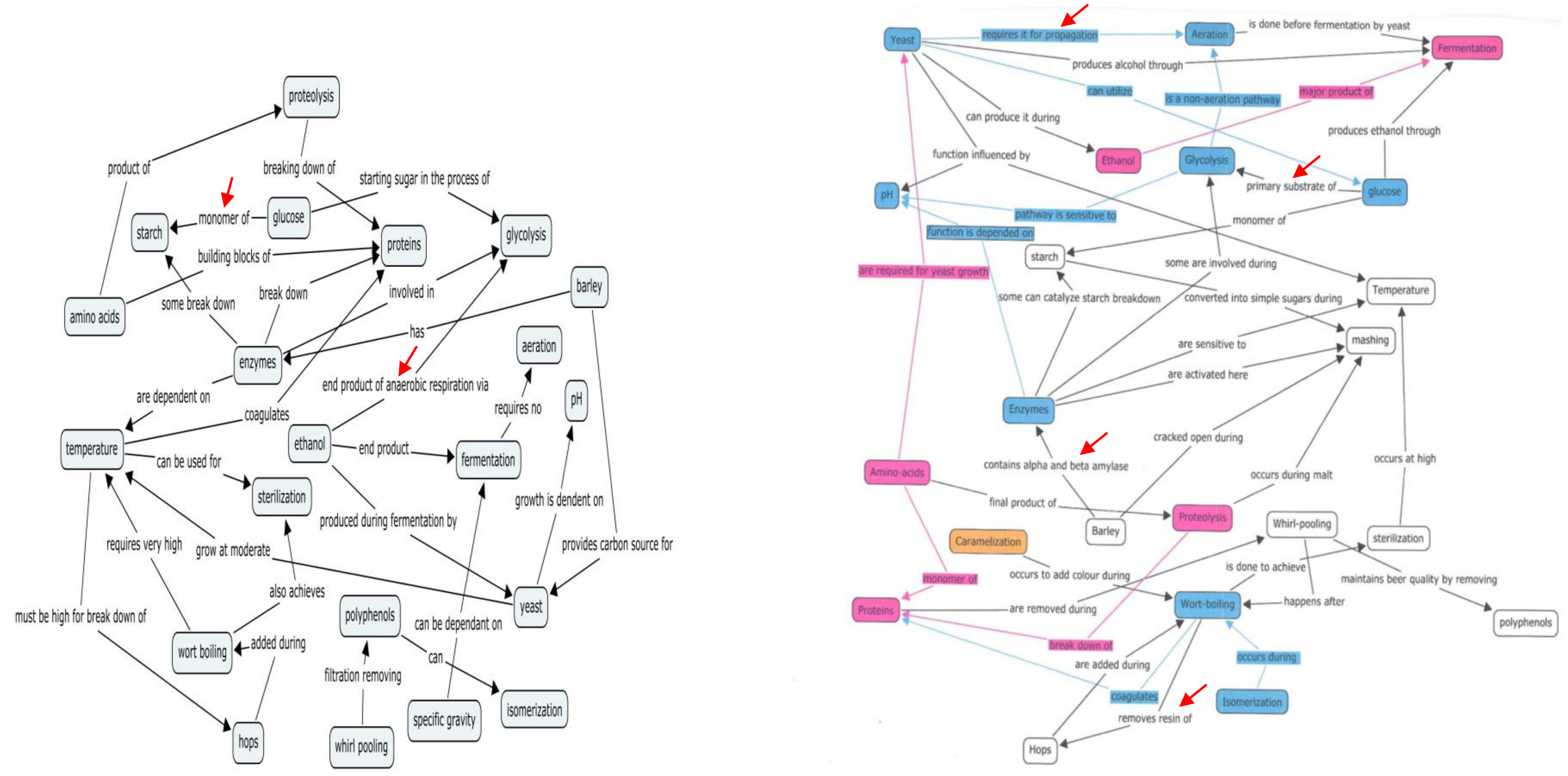
***Qu. –** question in Appendix 3

As illustrated by above quote, in the pre-test, the student was able to briefly state what occurs during mashing and boiling, whereas, in the post-test, he/she was able to elaborate, in great detail, what happens during these processes. Student B had the ability to i) explain the effects and significance of the different temperature profiles on enzyme activity in mashing and ii) indicate the importance of temperature in boiling. The student was able to apply her factual knowledge in order to explain the importance of temperature in brewing. Since the observational data showed that student B made an effort to learn from the practical (Section 4.1.1), it can be suggested that the student's high commitment, attitude and motivational levels helped her to better understand the brewing process.

Student B's post-test concept map (fig. 9) also revealed an improvement in the learner's conceptual understanding and integration of brewing concepts as compared to the pre-test map. The student was awarded an overall score of 18 for the pre-test concept map and 30 for the post-test map; this is because the post-test map was more coherent and expressive showing more correct propositions and logical linking words, similar to those included in the researcher's concept map (Appendix7). Concept maps allow an individual to create a picture of their understanding of concepts of a particular topic and enable them to indicate relationships between concepts. This gives individuals an opportunity to discover where their "deepest knowledge lies and where gaps in their understanding are" (Hancock, 2006). Thus student B's post-test map revealed that the student's understanding of brewing concepts and the relationship between concepts had improved by the end of the TLS.

Examining the concept maps (fig. 9) more closely regarding individual concepts, in the pre-test, the student did not include concepts such as caramelization (highlighted in orange in post-test map) probably due to the fact that she did not understand the concept and how it relates to other brewing concepts. However, in the post-test, the student correctly indicated that caramelization occurs during wort-boiling in order to add colour to the wort. Moreover, the post-test map shows more new correct propositions (highlighted in blue colour in post-test), thus suggesting a developed understanding of these concepts and their relationships. Furthermore, the student showed i) a few propositions (highlighted in pink in the post-test) that are similar to the researcher's concept map (see Appendix 7); and ii) used more expressive scientific linking words (red arrows). Research has revealed that as student's understanding of the integration of concepts improves, the use of general ambiguous linking words is also replaced by sound scientific words (Kharatmal and Nagarjuna, 2006). This constitutes strong evidence that the student improved their understanding of the brewing process.

Overall, the results showed that students B, D and K exhibited a gradual conceptual change from mainly knowledge of factual information (pre-test) to being able to reason with concepts and construct explanations (post-test and interviews). The students also retained their sound knowledge they gained from the TLS (Interviews).



Pre- test | **Post-test**

Figure 9: Student B's pre- & post tests concept maps. The red arrows indicate more expressive scientific words.

This suggests that the TLS was most effective in improving the students' understanding of the brewing process, besides giving them enjoyable learning experience as demonstrated by their positive attitude and high motivational levels (Section 4.1.1). This supports the idea that learning occurs more readily as an active and not a passive process. Also that, according to the constructivist theory of learning, meaningful learning occurs when students are involved in active cognitive processes which include being aware of relevant "incoming information", selecting the relevant information and organizing it into "coherent representations" and then integrating the selected, organized information with knowledge from the long term memory (Mayer, 2002; Moreno and Mayer, 2005; Anderson and Schönborn, 2008). In the case of these students this approach to learning was also evident in their outstanding performance in their other microbiology courses (Section 4.1.5).

4.2.2 Learners who participated actively in the brewing practical but did not reveal an enhanced understanding of the brewing process (Students G, H & J)

Students G, H & J also showed high attitudinal and motivational levels, interacted with other students, participated and worked hard during the brewing practical (Section 4.1.1). Furthermore, in their evaluation questionnaire, the learners pointed out that i) the brewing TLS assisted in developing their understanding and visualization of the brewing process, ii) they enjoyed the practical, iii) made an effort to learn from the practical and iii) interacted with other students (Section 4.1.2). However, the students' motivation levels and evaluation responses do not correlate with their performance throughout the TLS. Their conceptual understanding of the brewing process did not improve and they did not retain the knowledge they gained from the TLS. Table 14 below shows a summary of the students' conceptual status during the TLS.

Table 14: The conceptual status of students G, H and J

Brewing Concept	Overall Pre-Test (Sound/Difficulty)	Overall Post-Test (Developed/ No change)	Pre-Test Concept Map (Sound/unsound links)		Post-Test Concept Map (More sophisticated/unsound links corrected)			Conceptual Development during TLS?	Remediation of any Difficulties Yes/No		Retention of understanding after 2 months Yes/No
STUDENT G			Ambiguous map. Overall score=17		Ambiguous map. Overall score= 17				**R**	**NR**	
			No. SL	**No. USL**	**No. MSL**	**No. SL**	**No. USLC**				
Substrate	S	S	1	2	0	1	0	NC	-	-	N
Enzymes	S	S	3	1	0	0	0	NC	-	-	N
pH	S	S	0	1	0	0	0	NC	-	-	N
Temperature	S	S	0	0	0	0	0	NC	-	-	N
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Sterility	S	S	0	0	0	0	1	NC	-	-	N
Water quality	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Process	S	S	1	2	0	1	0	NC	-	-	N
Specific gravity	D	D	0	0	0	1	0	NC	-	NR	N
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	S	S	0	0	0	1	0	NC	-	-	N
Isomerization	S	S	0	0	0	0	0	NC	-	-	N
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	NE	S	NE	NE	NE	NE	NE	NC	-	-	N

Caramelization	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Ingredients	S	S	5	3	0	1	0	NC	-	-	N
Products	S	S	0	2	0	0	0	NC	-	-	N
STUDENT H			Ambiguous map. Overall score=14		Ambiguous map. Overall score=15						
Substrate	S	S	2	4	0	1	0	NC	-	-	N
Enzymes	S	S	4	1	0	2	0	NC	-	-	N
pH	S	S	1	1	0	0	0	NC	-	-	N
Temperature	S	S	1	0	0	1	0	NC	-	-	N
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Sterility	S	S	0	1	0	0	0	NC	-	-	N
Water quality	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Process	S	S	3	2	0	1	0	NC	-	-	N
Specific gravity	S	S	0	1	0	0	0	NC	-	-	N
Solubility	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Stoichiometry	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	S	S	0	0	0	0	0	NC	-	-	N
Isomerization	NE	S	0	1	0	0	0	NC	-	-	N
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Caramelization	NE	S	0	1	0	0	0	NC	-	-	N
Ingredients	S	S	3	1	0	3	0	NC	-	-	N
Products	S	S	3	1	0	2	0	NC	-	-	N
STUDENT J			Ambiguous map. Overall score= 13		Ambiguous map. Overall score= 14						
Substrate	S	S	2	1	0	1	0	NC	-	-	N
Enzymes	S	S	3	1	0	2	0	NC	-	-	N
pH	S	S	1	0	0	0	0	NC	-	-	N

Temperature	S	S	1	0	0	2	0	NC	-	-	N
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Sterility	NE	S	1	2	0	1	0	NC	-	-	N
Water quality	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Process	S	S	2	0	0	2	0	NC	-	-	N
Specific gravity	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	S	S	NE	NE	NE	NE	NE	N	-	-	N
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	S	S	0	1	0	0	0	NC	-	-	N
Isomerization	S	S	0	1	0	0	0	NC	-	-	N
Contamination	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Precipitation	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Caramelization	S	S	0	1	0	0	0	NC	-	-	N
Ingredients	S	S	3	0	0	3	0	NC	-	-	N
Products	S	S	1	0	0	2	0	NC	-	-	N

***Key: S**- sound, **D-** difficulty, **NC-** no change, **SL-** sound link, **USL-** unsound link, **R-** remediation, **NR-** no remediation, **MSL-**more sophisticated links, **USLC-** unsound links corrected, **CD-** conceptual development, **NC-** no conceptual development, **NE-** not established.

As shown in table 14, students G, H and J did not portray an improved conceptual understanding of the brewing process during the TLS. Moreover, unlike the first group (students B, D and K) that retained their brewing knowledge two months after the brewing practical, students G, H and J did not remember most of the knowledge they had been taught during the brewing practical. In addition, their difficulties were not remediated while both their pre- & post test maps were ambiguous, with the majority of the links being either incorrect, not established (NE) or vague. Since students G, H and J all exhibited similar conceptual trends, and in the interests of brevity, only student G’s conceptual profile will be discussed in greater depth as representative of this group’s conceptual profile.

Student G's Profile throughout the TLS

Like student J, student G experienced the BPR difficulty in the pre- & post test and showed no remediation. The following quotations were provided by student G in the pre- & post tests:

Pre-test response	Post-test response
***Qu. 6b (i):** "SG [specific gravity] - the amount of sugar used by yeast cell to produce ethanol."	**Qu. 6b (i):** "Final SG represent (represents) the amount of sugar present in the wort that can be fermented by yeast."

***Qu.** question in Appendix 3

The above quotes suggest that the final specific gravity value is a measure of the amount of fermentable sugars that can be fermented by the yeast to produce ethanol. This is not correct as the final specific gravity value signifies the amount of non-fermentable sugars present in solution after fermentation is complete (propositional statements, question 6b (i), Appendix 5). What is even more interesting is the fact that although the student's motivation and commitment levels were high during the brewing practical, the learner retained the difficulty in the post-test. For this reason, interviews were conducted to examine the possible source (s) of the learner's difficulty. The following quote was provided during the interview:

> ***I***: "Can you please explain your answer."
>
> ***S:*** "Wait, let me think, [pause], yes you see, OG (original gravity) is taken before fermentation to see how much sugars we have and then FG (final gravity) is taken after fermentation to see how much sugar was converted to ethanol."

The above statements imply that FG is a measure of the amount of sugar converted to ethanol. The fact that student G retained the BPR difficulty even after participating in the brewing practical was unexpected. This is because during the practical; the student was supposed to record the OG and FG and use the two values to calculate the alcohol percentage of their beer. In so doing, it was expected that the student would learn and understand the differences between OG and FG and their significance in brewing and hence correct the BPR difficulty. BPR is a new type of difficulty that has to date not been discovered in any research hence it was classified at level 1 of the framework (Grayson *et al*., 2001).

Student G showed great participation (Section 4.1.1) during the brewing practical: the student attempted to ask and answer questions, interacted with other students, and did most of the work. For this reason, the researcher thought the student would gain more new knowledge which would assist in improving her prior conceptual understanding of the brewing process. Instead, the student's pre-test, post-test, and one-on-one interview responses did not portray any improvement in the student's understanding of the brewing process. For instance, the student provided the following answers when asked to explain the importance of the wort boiling processes in brewing (Appendix 3):

Pre-test response	Post-test response
***Qu. 4:** "Adjustment of pH, evaporation of volatile compounds- DMS is lost during boiling. Sterilizing the wort kills all the unwanted microbes"	**Qu. 4**: "Adjustment of pH, addition of hops is done because hops add bitterness, DMS is evaporated."

***Qu.-** question in Appendix 3

Comparing the pre- & post tests responses shows that the student's factual knowledge with regards to wort-boiling did not increase. Furthermore, although the pre& post tests responses indicate that the learner knew some processes that occurred during the wort boiling processes, in the post-test, the learner was still not able to explain the significance of these processes in brewing. For instance, student G knew that DMS was evaporated during wort boiling (*factual information*), but the student failed to explain i) why it was necessary to evaporate DMS and ii) the affect this will have on the final product, beer.

One of the facets of conceptual understanding is having the ability to apply the acquired knowledge (**C** in fig. 7) to provide coherent explanations (**R-C** in fig. 7) when solving problems or explaining phenomena. Therefore, if student G understood the wort-boiling process, her knowledge of the wort-boiling process would have increased in the same way as student B's wort-boiling knowledge increased (Section 4.2.1). Moreover, the student would have been able to transfer and apply prior wort-boiling knowledge (**C** in fig. 7) to explain the significance of the various wort-boiling processes in brewing. During the one-on-one interviews, the student was also not able to explain the importance of wort-boiling and how it affects the final beer product, as illustrated by the following statements:

> ***I:*** "Use the diagram provided to explain how each stage contributes to the final product." (Phase 2, probe 2a, Appendix 12)
>
> ***S:*** "[..] you add your hops for bittering units and aroma, mhh [thinks for a while] and the wort is sterilized, I cannot remember everything, we did this a long time ago [..]"

Once again, instead of explaining the affects of wort-boiling processes on the final product, the student listed the wort-boiling processes, suggesting that the student's understanding of the brewing process, especially the wort boiling process, is inadequate. The use of words such as "*cannot remember*" suggests that the student might have memorized details of the wort-boiling processes for the pre- & post tests and, since the knowledge was partially stored in the short term memory, it was soon forgotten. Furthermore, the fact that student G could state brewing facts but was not able to transfer and apply their knowledge to explain situations also suggests that the learner rote learned for the tests. Rote learning involves memorizing information without in-depth understanding, therefore this makes it difficult to transfer and apply the information/knowledge to other areas[4]. It must be noted that in order to understand the wort boiling process, one has to understand processes such as *isomerization*, *caramelization, volatilization, sterilization, and acidification* (see Chapter 2). As a result the fact that student G's understanding of the wort boiling process did not improve implies that the student's understanding of the aforementioned processes did not develop either.

[4] http://homeworktips.about.com/od/glossary/g/rote.htm

Student G's conceptual understanding of the whirl-pooling process did not improve either: this is because in the post-test, i) the student's factual knowledge in connection to the whirl-pooling process did not increase and ii) the learner was still not able to explain the significance of this process in brewing. The following responses were provided by the student when asked to elucidate the importance of whirl-pooling in brewing:

Pre-test response	Post-test response
***Qu. 3:** "Whirl-pooling coagulates proteins and separates the hop trub from the wort to give a clear beer."	**Qu. 3:** "Whirl-pooling form (forms) and settles the trub to produce clear wort. It also coagulate (coagulates) the proteins [...]"

***Qu.**- question in Appendix 3

When comparing the pre- & post tests responses, one can realize that there is not much of a difference in the students' whirl-pooling knowledge. This therefore serves as an indication that the learner's knowledge of whirl-pooling did not improve during the TLS. What is more interesting is the fact that even in the post-test; the student was still not able to explain the significance of coagulating proteins during whirl-pooling. The process of whirl-pooling encompasses knowledge of concepts such as solubility, precipitation and coagulation (see Chapter 2); as a result, the fact that the student's conceptual understanding of the whirl-pooling process did not improve suggests that the student's understanding of the mentioned concepts may not have developed.

Furthermore, the student's understanding of the mashing process and its significance in the brewing process did not develop. This was supported by the following replies when probed to explain the brewing conditions that led to the production of thin and full bodied beers:

Pre-test response	Post-test response
***Qu.7b (i & ii):** "Different enzymes are activated during mashing. These enzymes are activated at different temperatures. The alpha-amylase is activated at 65°C and the beta-amylase is activated at 70°C. The different temperature profiles and the different enzymes produce beers with a thin or full body. [..]"	**Qu.7b (i & ii):** "During mashing different temperatures are used. Alpha & beta amylases are activated at different temperatures. This affects the body of the beer because the beer produced will have a thin or full body."

***Qu.-** question in Appendix 3.

One again, the pre- & post test responses are more or less the same; both responses correctly indicate that the different temperature profiles and enzymes activated in mashing contribute to the body of the brewed beer. However, the responses do not stipulate how temperature profiles and alpha and beta amylases contribute towards the production of either a thin- or full-bodied beer. As a result, this is an indication that the student's understanding of the mashing process did not develop during the TLS. In order to understand the mashing process, one has to know i) the importance of the different temperature profiles, ii) the temperatures at which alpha and beta amylases are activated and iii) how temperature and these amylases contribute to the body of the brewed beer (see Chapter 2 & propositional statements, question 7b (i & ii) Appendix 5).

During the brewing practical, the students were expected to use the OG and FG values in order to calculate the alcohol percentage of their beer. This task was aimed at developing students' understanding of specific gravity and how its values can be used in order to calculate the alcohol percentage of beer. In the pre-test, the student failed to calculate the alcohol percentage using the provided OG, FG and other relevant values (probe 8, Appendix 3). However, although in the post-test the student managed to correctly calculate the alcohol percentage of beer, student G failed to solve the same probe in the interviews. The reason for this was that the student claimed to have forgotten how to use the formula and the specific gravity values to calculate the alcohol percentage of beer, showing poor retention of knowledge. Based on this, therefore, it was deduced that the student probably didn't ever fully understanding how to determine the alcohol percentage having rote learnt the algorithm, and thus more easily forgot how to do the calculation.

The student's poor understanding of the brewing process was also reflected in his/her pre- & post test concept maps (fig. 10). As shown in section 4.1.4, student G was awarded a score of 17 both in the pre- & post test concept maps, showing no improvement. Both the pre- & post test maps were confusing, contained incorrect propositions (highlighted in red colour) and general unclear words were used as linking words (pink arrows). The maps were also vague and showed a poor integration of brewing concepts.

When comparing the two concept maps (fig. 10), one realizes that in both cases the majority of the linking words are general in nature. General words do not clearly specify relations between concepts as a result this leads to vague concept maps that are difficult to understand. For example, both in the pre- & post maps, the student used the word "*of*" as a linking word between barley and mashing, which does not clearly specify the relationship between the two concepts. The use of general words instead of scientifically-based propositions, in concept map construction is common, however, it is expected that as one's knowledge and understanding develops, then the use of such words should be overdrawn by clear scientific linking words and statements (Kharatmal and Nagarjuna, 2006). Consequently, the fact that the learner's pre- & post test maps consisted entirely of general linking words shows that the learner's understanding of brewing concepts and their relationships did not develop during the brewing practical.

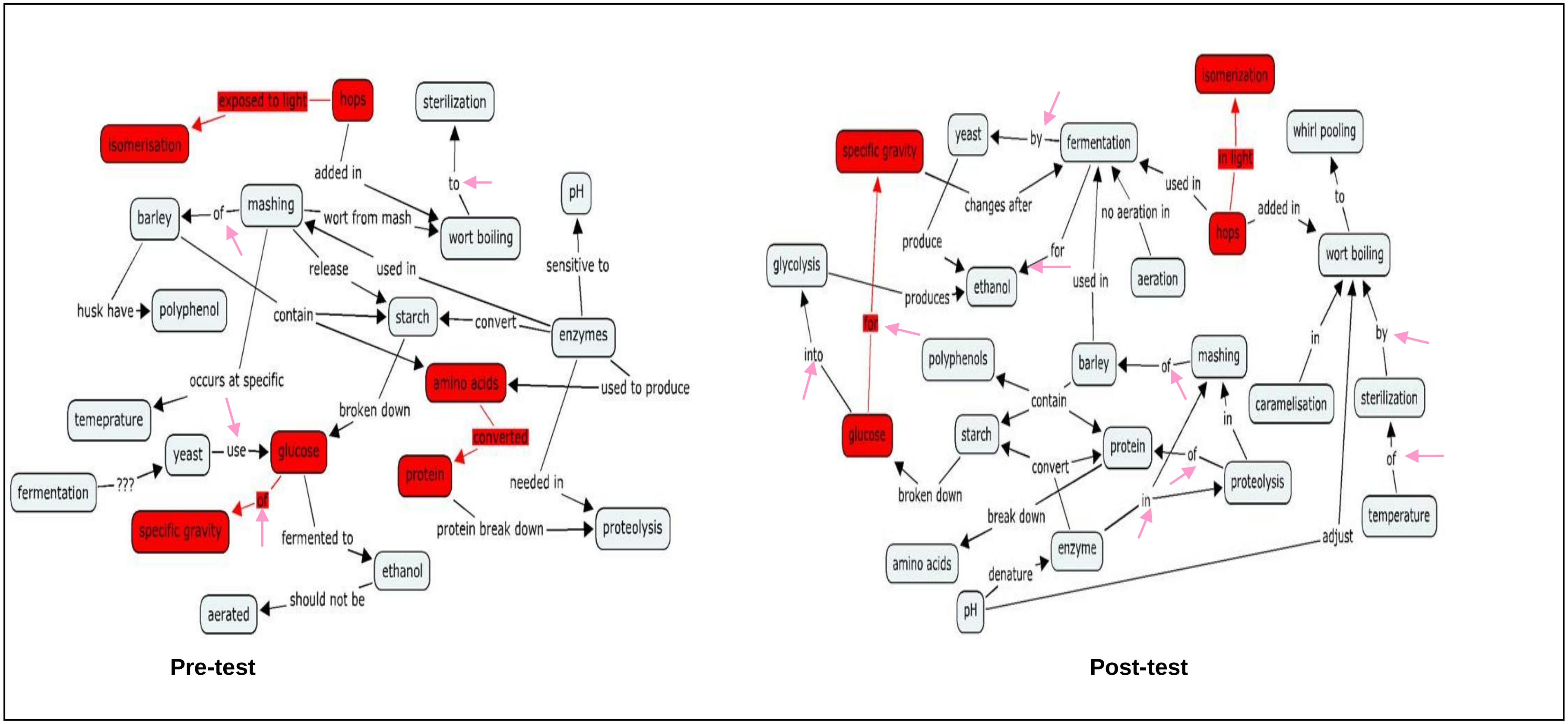


Figure 10: Student G's pre- & post tests concept maps.

Generally speaking, students G, H and J were committed and motivated during the TLS, however, their prior brewing knowledge did not improve during the TLS, and thus their visual and cognitive skills did not develop either. This meant that the students were unable to transfer and apply their prior knowledge to explain phenomena and construct expressive concept maps. This therefore shows that high motivation and commitment levels do not necessarily guarantee conceptual development. It is important to state that these students showed an excellent performance in other microbiology courses (Section 4.1.5), thus suggesting that their attitudinal and motivational levels were high but that the brewing practical with all its difficult concepts was perhaps more cognitively demanding.

4.2.3 Learners that did not show interest in the brewing practical and therefore did not develop their understanding of the brewing process during the TLS

According to the observational results shown in section 4.1.1, students A, C, E & I were not interested in the brewing practical. These students did not attempt to ask or answer any questions posed by the demonstrator (Appendix 8); they did not attempt to make any effort to learn from the practical and during the brewing practical they just sat around watching the other students do the work. These students mainly chatted about "*weekend events"*, played cards while one of them spent most of the time at a near-by supermarket. For these reasons, the students had the lowest observational score of 18. Contradictorily, in their evaluation questionnaire (Section 4.1.2), the students indicated that they i) enjoyed the brewing practical; ii) liked the practical since it helped improve their understanding and visualization of the brewing process, iii) interacted with other students and iv) made an effort to find solutions to problems encountered during the practical, possibly because they wanted to try and hide their true feelings in case this counted against them when graded. Whereas the students' observational results correlate with their poor conceptual performance their evaluation responses therefore did not. The students' overall conceptual status is presented in table 15 below.

Table 15: The conceptual status of students A, C, E and I

Brewing Concept	**Overall Pre-Test (Sound/Difficulty)**	**Overall Post-Test (Developed/ No change)**	**Pre-Test Concept Map (Sound/unsound links)**		**Post-Test Concept Map (More sophisticated/unsound links corrected)**			**Conceptual Development during TLS?**	**Remediation of any Difficulties Yes/No**		**Retention of understanding after 2 months Yes/No**
STUDENT A			Ambiguous map. Overall score= 10		Ambiguous map. Overall score= 10				**R**	**NR**	
			No. SL	**No. USL**	**No. MSL**	**No. SL**	**No. USLC**				
Substrate	S	S	3	1	0	2	0	NC	-	-	N
Enzymes	S	S	2	0	0	3	0	NC	-	-	N
pH	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Temperature	S	S	2	0	0	2	0	NC	-	-	N
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Sterility	S	S	1	0	0	0	0	NC	-	-	N
Water quality	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Process	S	S	3	1	0	3	0	NC	-	-	N
Specific gravity	S	S	0	0	0	0	0	NC	-	-	N
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Isomerization	S	S	0	0	0	0	0	NC	-	-	N
Contamination	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Precipitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Caramelization	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Ingredients	S	S	3	4	0	2	0	NC	-	-	N
Products	S	S	4	2	0	3	0	NC	-	-	N

STUDENT C			Ambiguous map. Overall score= 11		Ambiguous map. Overall score= 11						
Substrate	S	S	5	0	0	3	0	NC	-	-	N
Enzymes	S	S	3	0	0	1	0	NC	-	-	N
pH	NE	NE	0	0	0	1	0	NE	-	-	NE
Temperature	S	S	1	0	0	0	0	NC	-	-	N
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	D	D	NE	NE	NE	NE	NE	NC	-	NR	N
Sterility	S	S	0	1	0	0	0	NC	-	-	N
Water quality	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Process	S	S	0	2	0	0	0	NC	-	-	N
Specific gravity	NE	NE	0	1	0	0	0	NE	-	-	NE
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Aeration	NE	NE	0	1	0	0	0	NE	-	-	NE
Isomerization	NE	S	0	0	0	0	0	NC	-	-	N
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Caramelization	NE	NE	0	0	0	0	0	NE	-	-	NE
Ingredients	S	S	4	1	0	2	0	NC	-	-	N
Products	S	S	0	1	0	1	0	NC	-	-	N
STUDENT E			Ambiguous map. Overall score= 9		Ambiguous map. Overall score= 10						
Substrate	S	S	2	1	0	2	0	NC	-	-	N
Enzymes	S	S	3	0	0	3	0	NC	-	-	N
pH	S	S	1	0	0	1	0	NC	-	-	N
Temperature	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	S	S	NE	NE	NE	NE	NE	NC	-	-	NE
Sterility	NE	S	0	0	0	1	0	NC	-	-	N

Water quality	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Process	S	S	2	3	0	3	0	NC	-	-	N
Specific gravity	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Aeration	S	S	1	1	0	1	0	NC	-	-	N
Isomerization	S	S	1	1	0	0	0	NC	-	-	N
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Caramelization	S	S	0	0	0	0	0	NC	-	-	N
Ingredients	S	S	3	0	0	3	0	NC	-	-	N
Products	S	S	2	3	0	3	0	NC	-	-	N
STUDENT I			Ambiguous map. Overall score=12		Ambiguous map. Overall score= 12						
Substrate	S	S	3	2	0	1	0	NC	-	-	N
Enzymes	S	S	3	0	0	3	0	NC	-	-	N
pH	S	S	1	0	0	0	0	NC	-	-	N
Temperature	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Time	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Coupling	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Sterility	NE	S	0	1	0	1	0	NC	-	-	N
Water quality	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Process	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Specific gravity	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Solubility	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Stoichiometry	NE	S	NE	NE	NE	NE	NE	NC	-	-	N
Sanitation	S	S	NE	NE	NE	NE	NE	NC	-	-	N
Aeration	S	S	1	2	0	0	0	NC	-	-	N
Isomerization	S	S	0	0	0	0	0	NC	-	-	N
Contamination	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE
Precipitation	NE	NE	NE	NE	NE	NE	NE	NE	-	-	NE

Caramelization	S	S	0	2	0	0	0	NC	-	-	N
Ingredients	S	S	2	1	0	2	0	NC	-	-	N
Products	S	S	3	1	0	2	0	NC	-	-	N

***Key: S**- sound, **D**- difficulty, **NC**- no change, **SL-** sound link, **USL-** unsound link, **R-** remediation, **NR-** no remediation, **MSL-** more sophisticated links, **USLC-** unsound links corrected, CD- conceptual development, **NC-** no conceptual development, **NE-** not established

Table 15 shows that students A, C, E and I's conceptual understanding of the brewing process and related concepts did not improve during the TLS. As in the case of the second group (students G, H and J), students A, C, E, and I did not retain most of the knowledge they had been taught during the brewing practical. Also because of their poor understanding of the brewing concepts, the students' difficulties were not remediated. Also the students' pre- & post test maps were ambiguous in that the majority of the links were either incorrect, not established (NE) or vague. In addition, like the second group, students A, C, E and I's post- test maps did not contain any sophisticated sound links. Moreover, most concepts were not established, suggesting an inadequate understanding of these concepts and their relations to other concepts. Since students A, C, E and I exhibited similar conceptual trends, only student C's conceptual profile will be discussed further as being representative of the whole group.

Student C's profile throughout the TLS

As indicated in section 4.1.3, student C portrayed the R difficulty in the pre- & post-tests. The following erroneous statements were provided by the student in the pre- & post tests:

Pre-test response	Post-test response
***Qu. 2a:** "[..] This co-factor, NAD^+, are [is] essential for the production of 1,3 bisphosphoglycerate reaction but not the production of ethanol reaction. When there is NAD^+, the production of ethanol reaction will not occur."(**R**)	**Qu. 2a:** "Ethanol will not be produced because only NAD^+ is present and there is no NADH". (**R**)

***Qu.**- question in Appendix 3

It is evident from the above quotes that student C's conceptual knowledge of glycolytic reactions and coupling is inadequate. The learner seems not to understand that in the presence of NAD^+, ethanol would be produced because NAD^+ is reduced to NADH (McKee and McKee, 1999). Therefore, since glycolytic reactions are consecutively linked, the NADH produced would be used as a co-substrate for the production of ethanol (see propositional statements, question 2a, Appendix 5). The fact that the student had a poor understanding of glycolytic reactions is strange because as indicated in Chapter 3 (Section 3.3), this student was taught metabolism throughout undergraduate level. It was therefore assumed that student study factors (e.g. low motivation levels) contributed towards the student's inadequate knowledge of glycolytic reactions. Since the **R** difficulty was experienced in the post-test, interviews were conducted in order to track the source (s) of this difficulty. The following statements were provided by student C during the interviews:

> ***I***: "Explain why you stated that ethanol would not be produced in the presence of NAD^+"
>
> ***S:*** "I'm [I am] not sure why I'm [I am] saying this, [..], but I think if NAD^+ is present, then this reaction will continue, [points to the reaction involving the production of 1,3 bisphosphoglycerate from glyceraldehyde-3-phosphate], ethanol will not be produced because you see [points to the last reaction in which acetaldehyde is converted to ethanol], this reaction needs NADH, so there is no NADH."

The above statement shows that student C did not comprehend that glycolytic reactions are consecutively linked and thus the product of one reaction is used as a substrate for subsequent reactions. This therefore suggests that the student did not understand the concept of coupling and the glycolysis pathway. Moreover, the above quotes indicate that the student was only thinking of the local effects of NAD^+ and failed to think of its global effects on the entire glycolysis pathway. In 2002, Anderson and his colleagues discovered that Biochemistry students had conceptual and reasoning difficulties with the functioning of metabolic pathways, specifically, the glycolysis pathway. The study revealed that students believed glycolytic reactions are independent, that is, the enzyme inhibition of one reaction would not affect reactions before and after the point of inhibition. This showed that the students were only thinking of the local effects of enzyme inhibition on glycolysis and did not think of the global effects of enzyme inhibition on the glycolysis pathway throughout the system. Based on the latter statement, the current author had suspected that students might reveal some localised reasoning difficulties in relation to the glycolysis pathway, thus the **R** difficulty was classified at level 2 of the four- level framework (Grayson *et al.,* 2001).

Student C also exhibited the BP difficulty in the pre- & post tests. An example of the learner's quotations that illustrated the BP difficulty is provided below:

Pre-test response	**Post-test response**
***Qu. 3:** "If the brewer forgets to whirl-pool the wort, […], the enzyme that convert [converts] sugar to ethanol will be denatured by the hot wort."	**Qu. 3:** "[..] Whirl-pooling is important because it helps to cool down the wort [...]

*__Qu-__ question in Appendix 3

The above quotes suggest that student C did not have a good conceptual understanding of the whirl-pooling process. In order to comprehend the whirl-pooling process, an individual has to understand concepts such as solubility and precipitation. The fact that student C did not understand this process indicates that the learner did not understand these concepts. Since the BP difficulty was also experienced in the post-test, interviews were conducted in order to locate the source (s) of the learner's difficulty. The student provided the following statement:

I: "What is the significance of whirl-pooling in brewing?"

S: "mhh [thinks for a while] I know that it cools the wort and this is important because yeast has to be added in a cooled wort [..]"

The above statement reinforces the idea that wort is cooled during the process of whirl-pooling and thus serves to show that the student retained the unsound knowledge because the student's conceptual knowledge of whirl-pooling did not improve even after the hands-on brewing practical. This is surprising because during the practical students were expected to: cool the wort by running cold water through metal pipes found inside the kettle (metal heat exchangers); transfer the wort to the fermentor vessel once it has cooled down to below 10°C; and remove debris (solid particles settled by whirl-pooling) from the kettle. Through performing these tasks, students were expected to: understand that wort is cooled via cooling pipes and not whirl-pooling and notice that whirl-pooling encourages cold and hot breaks and the sedimentation of hop trub and coagulated proteins (propositional statements, question 3, Appendix 5). This suggests that the student didn't actually participate in this practical activity which is supported by the observational data that portrayed the student as being demotivated, not committed and showing no interest in contributing towards the activities of the brewing practical.

Besides these difficulties, comparison of the student's pre- & post tests responses revealed that the student's brewing conceptual knowledge did not develop during the TLS. For instance, the student provided the following replies when asked to explain the wort boiling process and its affects on the final beer product.

Pre-test response	**Post-test response**
***Qu. 4:** "Is to remove volatile compounds like DMS because it gives beer a sweet corn flavour, formation of flavour and colour, decreasing the pH of the wort, help to coagulate proteins/polyphenol complexes"	**Qu. 4:** "Removal of DMS because it has a sweet corn flavour, help to coagulation (helps in the coagulation) of proteins, sterilisation of the wort is good if the wort is contaminated by bag of bucks (bugs)"

***Qu. -** question in Appendix 3

When looking at the above responses, one can realise that there is not much of a difference between the pre- & post tests replies. In both responses, the student has stated similar facts and this indicates that the student's factual knowledge with regards to the wort boiling processes did not improve at all. Like student G, student C lacked the correct cognitive and visual skills to apply her existing wort boiling knowledge to explain its importance and impact on the final product, beer. As stated in chapter 2, wort boiling encompasses the knowledge of processes such as isomerization, precipitation, sterilization, caramelization and acidification. Therefore, the fact that the student's understanding of wort-boiling did not develop during the TLS indicates that her understanding of these processes did not improve either. Research has shown that conceptual understanding does not only involve the ability to memorise knowledge, instead it also entails the capability to understand the memorised knowledge in order to be able to apply the knowledge to explain phenomena such as the impact of wort boiling in brewing (Anderson *et al.,*2001).

When asked to explain the brewing conditions that might have led to the production of a thin- and a full-bodied beer, the learner provided the following answers:

Pre-test response	**Post-test response**
***Qu. 7b (i & ii):** "For a thin body, β-amylase is activated by the lower temperature used in mashing and for a full body, α-amylase is activated by the higher temperature used in mashing."	**Qu. 7b (i &ii) :** "The different temperature profiles [..], temperatures around 65°C cause a thin bodied beer and temperatures around 70°C cause a full bodied beer."

***Qu. –** question in Appendix 5

The above responses are true but vague because they do not clarify i) how low and high temperatures influence the production of thin and full bodied beers and ii) how alpha and beta amylases contribute towards the production of thin and full bodied beers. Once again the student's pre- & post test responses are similar; thus suggesting that her factual knowledge with regards to the mashing process did not improve during the TLS. Yet again, this might have been due to the fact that during one of the TLS activities (brewing practical), the student appeared disinterested in the brewing practical and her motivation and commitment levels were low (Section 4.1.1). Furthermore, the idea that student C was not able to elaborate on how temperature and enzyme activity contributed towards the body of the produced beer implies that her conceptual understanding of the mashing process was inadequate.

Although in the post-test the student was able to correctly calculate the alcohol percentage, w/w and v/v, the student failed to solve the same problem during the interviews and provided the following explanation:

> ***I***: "Why are you not able to solve this problem yet you were able to solve it in the post-test?" (Phase 1, probe 1c, Appendix 12)
>
> ***S:*** "I only memorised the formula and how it works for the test and now I have forgotten everything."

It is obvious from the above quote that student C rote learned the formula required to answer question 8 and this does not lead to improved understanding of a domain. Moreover, rote learned knowledge is usually not retained over time as evidenced by the student C's response. Besides probing student's conceptual understanding via explanatory tasks, students were asked to draw a brewing concept map. This was done in order to investigate students' integration skills. Once again, student C's pre- & post test maps revealed that the student's conceptual understanding of the brewing process did not progress during the TLS. In the same way as student G, student C's inadequate understanding of the brewing process resulted in the construction of unclear maps (fig. 11) that show a poor integration of concepts.

Although the post-test concept map has more propositions when compared to the pre-test map, they both have ambiguous linking words (pink arrows), incorrect propositions (highlighted in red colour) and unused concepts (highlighted in green colour). The fact that the concept map has unused concepts and incorrect propositions shows a poor understanding of these concepts and their relationship to other brewing concepts. As before, student C has used general words to show relations between concepts which stems from confusion and vague understanding of the concepts. The reason being general words do not specify the precise relationships between concepts. For instance, in the pre- & post tests, the student used the word *inhibit* to show a relation between pH and enzymes. The problem with using this word is that it does not specify whether enzymes are inhibited by basic, neutral or acidic pH. Moreover, *inhibit* is an inappropriate word to use as a linking word between pH and enzymes because pH does not inhibit enzymes, instead it either *denatures* enzymes or *influences* their activity. It is true that students sometimes borrow the connecting words from their daily language (Kharatmal and Nagarjuna, 2006) and the use of such words often leads to ambiguity. However, it is expected that as students' knowledge and understanding of a particular domain improves, the use of general linking words should be replaced by the use of scientific words. Therefore, the fact that student C's final map consisted mostly of general linking words suggests that the student's conceptual understanding of the brewing process did not develop during the TLS.

Furthermore, student C's initial and final maps appeared fragmented (orange lines). That is, there were missing links between fermentation process related concepts (e.g. glycolysis and specific gravity) and other brewing concepts. This suggests that student C had conceptual gaps in their brewing knowledge. In 2006, Hancock discovered that third-year genetics students had fragmented knowledge with regards to statistics and genetics in that these students' concept maps showed missing links between statistics and genetics thus demonstrating conceptual gaps in the students' knowledge.

Overall, it appears as though students A, C, E and I lacked an in-depth knowledge of the brewing process because they were not able to provide detailed explanations when answering questions. Moreover, it is also evident that these students had sound basic brewing knowledge at the start of the TLS (as shown by the pre-test); however, this knowledge did not develop in the post- test probably because of their lack of interest in the exercise.

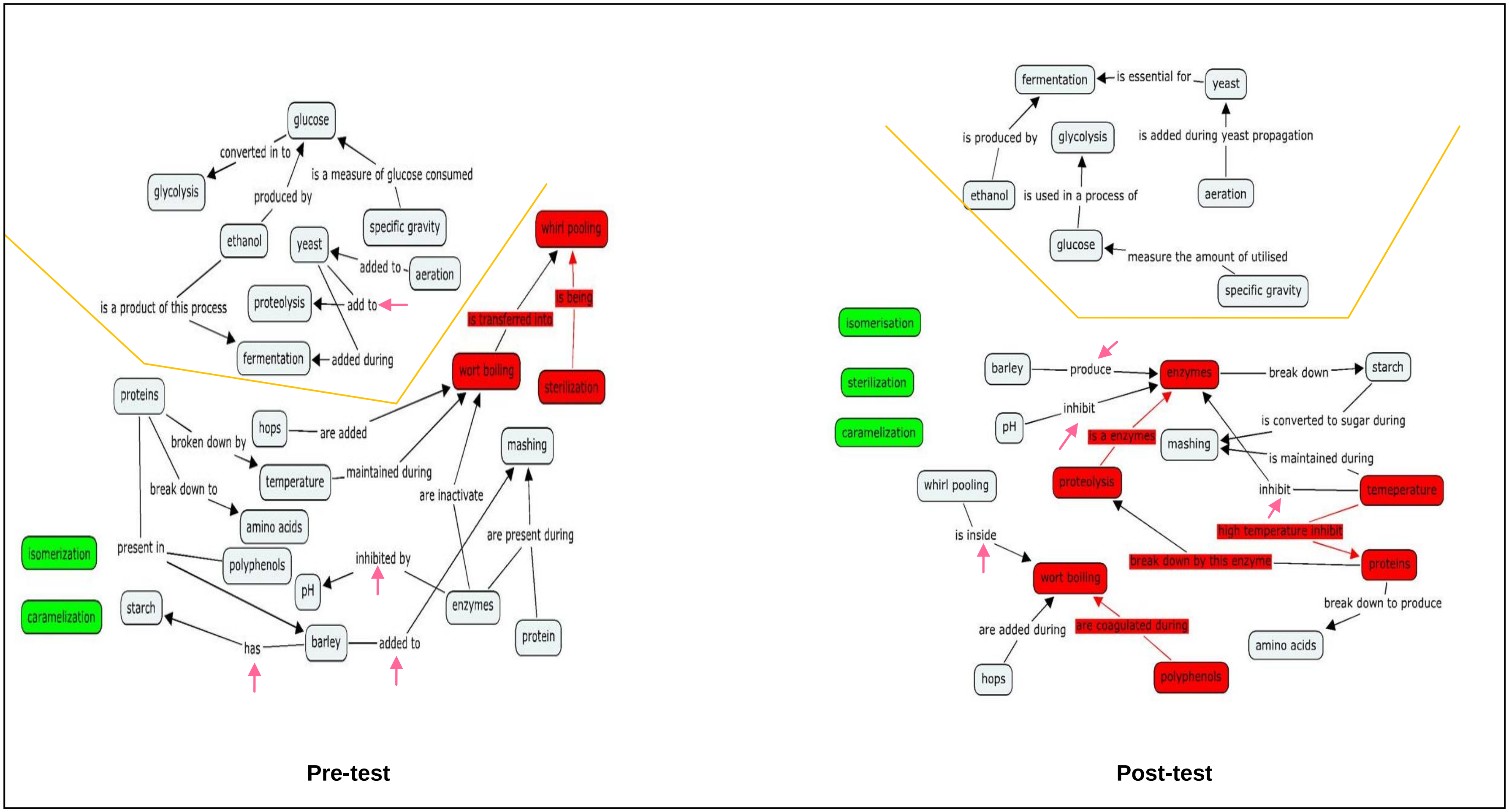


Figure 11: Student C's pre- & post test concept maps. Pink arrows show ambiguous linking words.

4.3 Summary and Conclusion

In general, students with the **R-type** difficulty appeared to not understand that reactions in glycolysis are linked via common intermediates. Consequently, students failed to visualise that the NADH formed from the reduction of NAD^+ is utilized as one of the reactants involved in the production of ethanol. This illustrates that the students only concentrated on the local effects of NAD^+ and ignored its global effects. On the other hand, learners who exhibited the **BP** and **BPR** difficulties seemed to have an inadequate conceptual understanding of the whirl-pooling process and specific gravity.

Some students' (B & K) difficulties were remediated during the TLS; however, some difficulties were hard to remediate and thus hindered the learning of sound brewing knowledge. Moreover, students B, D & K, who actively took part in the brewing practical, showed an improved understanding of the brewing process. However students (A, C, E & I) who portrayed low motivation and commitment levels during the brewing practical did not show an improved understanding of the brewing process. It must be noted that high commitment and motivation levels can certainly help students but does not guarantee an improved understanding of the brewing process. This was illustrated by students G, H and J who were actively involved in the brewing practical but did not show any improvement in understanding of the brewing process. Based on the results it can be confidently inferred that the brewing TLS was highly effective in developing students B, D & K's: i) prior brewing knowledge (**C** in fig. 7); ii) cognitive skills required for understanding brewing concepts (**R** in fig. 7); iii) visual skills required for relating the brewing apparatus to the brewing process (**R-M** in fig. 7); and the ability to use the brewing knowledge to correctly interpret, visualize and learn from the micro-brewery apparatus (**C-R-M** in fig. 7). However, more consideration needs to be given on how to motivate all students in the exercise so that all students achieve like this group (students B, D & K).

Chapter 5: General Discussion

5.1 Research Questions and Major Findings of the Current Study

The goal of this research was to address the following research questions:

1. What concepts are essential for understanding the process of beer brewing?
2. Did those students with sound conceptions develop deeper understanding during the TLS?
3. Did students show any conceptual difficulties with the brewing concepts?
4. Did any remediation of such difficulties occur during the TLS?
5. Did students show retention of (mis)understanding two months after the brewing practical?
6. What were students' attitudes and motivational levels like during the brewing practical?
7. How well did students rate their experiences of the whole TLS?
8. How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding?

5.1.1 Summary of the relationship between 3-dimensions of research results

The results obtained in this study (see Chapter 4) composed at least five dimensions of data, namely, those from (i) measurement of conceptual understanding, (ii) changes in conceptual understanding, (iii) retention of understanding, (iv) affects of attitude and motivation on conceptual understanding and (v) evaluation of the TLS by students. Of these five dimensions, conceptual understanding, conceptual change, attitude and motivation levels were awarded scores (see Chapter 3) thus making it easy to construct a visual representative (fig. 12) depicting the relationship between these dimensions.

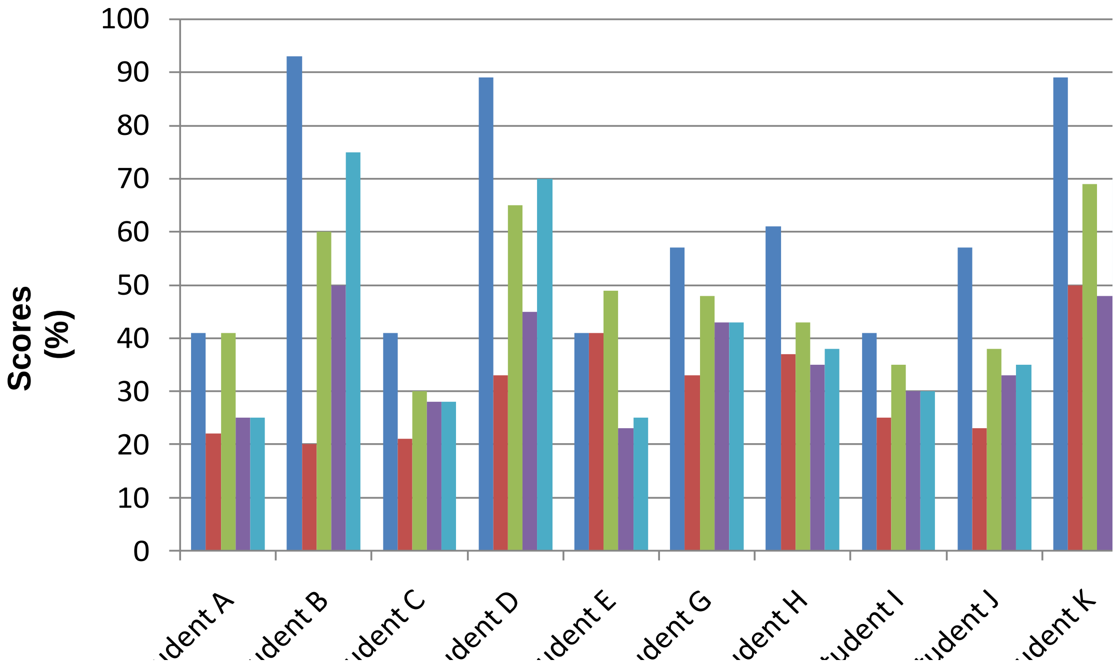


Figure 12: Relationships between observational score, pre- & post tests scores and pre- & post concept map scores.

It is evident from fig. 12 that attitude and motivation levels exposed during the brewing practical affected students' brewing conceptual understanding. As can be seen, high attitudinal and motivational levels (observational scores) resulted in high post test and post-concept map scores in the case of students B, D & K, whereas low attitudinal and motivational levels resulted in low post test and post-concept map scores for students A, C, E & I). However, there were exceptions in the case of students G, H & I where high attitude and motivation levels resulted in low post-test scores and post-concept map scores (student G, H & I). Detailed discussions of these findings are provided in the sub-sections below.

5.1.2 Research Question 1

What concepts are essential for understanding the process of beer brewing?

In response to research question 1, the following concepts were found to be crucial for understanding the process of beer brewing:

Brewing Concepts				
substrates	water quality	sterility	precipitation	process
enzymes	specific gravity	sanitation	caramelization	isomerization
pH	solubility	coupling	aeration	brewing ingredients
time	temperature	contamination	stoichiometry	products

5.1.3 Research Question 2

Did those students with sound conceptions develop deeper understanding during the TLS?

Pre- & post tests were used during the TLS in order to gather data on students' understanding of the brewing process. Comparison of students' pre- & post test responses revealed that students B, D & K developed deeper understanding of the brewing process during the TLS. These students' cognitive and visual skills developed because they were able to use their prior brewing knowledge to explain the various brewing stages, how these stages affect each other and their impact on the final beer product. Furthermore, these students' concept maps showed an improved understanding of brewing concepts and the relationship between the concepts. The maps were coherent, expressive, contained correct propositions, did not have missing links and the majority of the linking words were non-ambiguous. Thus these students integrated knowledge also developed which constitutes strong evidence for deep conceptual understanding (Anderson and Schönborn, 2008).

On the other hand, the evaluation of the pre- & post test demonstrated that students A, C, E, G, H, J & I's brewing knowledge did not improve during the TLS. The students lacked correct cognitive and visual skills to put their prior brewing knowledge in to active use. Therefore, this serves to show that knowledge in isolation (inert knowledge) (Grabinger and Dunlap, 1995, Anderson and Schönborn, 2008) is useless unless students possess the correct cognitive skills to use such knowledge to explain phenomena (Anderson and Schönborn, 2008). The latter statement can be compared analogically to a computer that has a hard-drive (knowledge) but does not have a processor (reasoning skills); without a processor, such a computer is useless (Anderson, pers. Comm.). What is more interesting is that the students' concept maps also illustrated that their conceptual understanding of brewing concepts did not develop during the TLS. This is because the students' pre- & post test concept maps showed a poor integration of brewing knowledge: the maps were unclear, fragmented, contained incorrect propositions, showed missing relations, and majority of the linking words were ambiguous. The fact that their maps were fragmented indicates they had conceptual gaps in their brewing knowledge, particularly between fermentation-process related concepts and other brewing concepts.

TLSs based on models have successfully been used to develop students' conceptual understanding of scientific concepts. For instance, Larsson *et al.,* (2010) used a TLS based on a physical model to develop students' understanding of viral self assembly. The results obtained demonstrated that students' understanding of self-assembly considerably improved during the TLS. This is because students' sound reasoning about self assembly and its random nature were significantly improved. Additionally, Kabapinar *et al.,* (2004) used a TLS based on a particle model of matter to improve students' conceptual understanding of solubility. Results indicated that students' understanding of solubility was developed during the TLS because they were able to use the model in order to explain solubility.

Similarly, concept maps have been used by various researchers in order to i) investigate students' understanding of scientific phenomena (e.g. Kharatmal, 2009), ii) examine knowledge gaps in students' understanding of scientific phenomena (e.g. Hancock, 2006) and iii) improve teaching (e.g. Kaiser, 2010). Concept maps have been used in microbiology to improve teaching (Kaiser, 2010), however, this study constitutes the first time that concept maps have been used in brewing microbiology to test for students' understanding of the brewing process. In genetics, Hancock (2006) used concept maps to study students' understanding of quantitative genetics. In the same way, Hancock (2006) discovered some students showed good integration of quantitative genetics whereas some showed a poor integration of concepts and gaps of knowledge between statistics and genetics, suggesting a poor understanding of variance and the connection between statistics and genetics.

5.1.4 Research Question 3

Did students show any conceptual difficulties with the brewing concepts?

Pre- & post tests were used to collect data in order to discover students' difficulties with the brewing process. Students' responses were analyzed via inductive analysis and three major difficulties were discovered. These difficulties were categorized as *reasoning difficulties* **(R)**, *brewing process-related difficulties* **(BP)** and *brewing parameters related difficulties* (**BPR**). Students A, B, C & D who showed the **R** difficulty believed ethanol would not be produced in yeast in the presence of NAD^+ but absence of NADH. Based on students' interview responses, the researcher deduced that this type of difficulty was probably caused by students' lack of understanding that two metabolic reactions can still be coupled in parallel via common intermediates (NADH and NAD^+) even if the reactions are "far removed" from each other in terms of metabolic sequence. Thus in the present example, the NAD^+ would be converted back to NADH by the Glyceraldehyde 3-phosphate dehydrogenase reaction so that it could be used in the alcohol dehydrogenase reaction. Thus the need in this case was to think for globally than locally about metabolic processes. The **R** difficulty was classified at level 2 of the four-level framework (Grayson *et al.,* 2001) since this is a novel difficulty although similar ways of reasoning have been shown by Grayson *et al.* (2001).

Students (B, C, H &K) with the **BP** difficulty believed whirl-pooling is done in order to cool the wort. Based on students' interview statements, it was proposed the **BP** difficulty was caused by the students' limited understanding of the whirl-pooling process. The **BP** difficulty is novel and has to date not been reported in any other study, therefore, it was classified at level 1 of the four- level framework of Grayson *et al.* (2001). The **BPR** difficulty was exhibited by students J & G who believed that the final specific gravity value is a measure of the amount of sugar converted to ethanol. Based on students' interview responses, it was suggested the **BPR** difficulty was caused by the students' poor understanding of specific gravity. The OG value is measured prior to fermentation because it is a measure of the total sugars present in wort; the FG value is measured after fermentation is complete in order to see how much sugar was unfermented. So it is possible that the students thought the FG value is measured after fermentation in order to reveal the amount of sugars converted to alcohol just in the same way the OG is measured before fermentation to measure the total amount of sugars in the wort. The **BPR** difficulty is a new type of difficulty which has thus far not been reported in any study. For this reason, it was classified at level 1 of the four-level framework of Grayson *et al.,* (2001).

5.1.5 Research Question 4

Did any remediation of such difficulties occur during the TLS?

The pre- & post test responses were compared in order to check if the observed difficulties were remediated during the TLS. Results obtained showed that, of the four difficulties, only the **BP** difficulty was remediated in the post- test. It must however be noted that four students (B, C, H & K) portrayed the **BP** difficulty in the pre-test, and only two (B & K) did not reveal the difficulty in the post-test. The fact that one of the four difficulties was remediated indicates that if the brewing TLS based on the micro-brewery apparatus is frequently used, it could assist even more students to better understand the brewing process and thus remediate the observed brewing difficulties.

The **R-** type difficulty is mainly related to the glycolysis pathway. Despite all ten students studying metabolism course at undergraduate level, most of them did not understand the glycolysis pathway at honours level. It is therefore possible that at undergraduate level the students rote learned the glycolysis pathway for tests, and since rote learned information is not stored in the long term memory, it is easily forgotten. For this reason, the students could not remember the glycolysis pathway, particularly the principle of parallel coupling. Therefore, the researcher suggests that the brewing lectures should cover an in-depth knowledge of the glycolysis pathway. This should assist in reducing the number of difficulties in this area and help prevent or remediate any existing difficulties.

5.1.6 Research Question 5

Did students show retention of (mis)understanding two months after the brewing practical?

Interviews were, amongst other reasons, conducted 2 months after the brewing exercise in order to investigate if the students had retained the knowledge they gained during the TLS. Results obtained indicated that students who showed high attitudinal and motivation levels during the practical, and thus showed an improved understanding of the brewing process (B, D & K), retained the brewing knowledge they gained throughout the TLS. These students could still remember and understand what they learned from the TLS two months after the brewing course was completed. The fact that students B, D & K could still remember the knowledge they gained during the TLS indicates a true conceptual understanding of the brewing process. This is because retention of knowledge is one of the cognitive skills required for conceptual understanding (Mayer, 2002). On the other hand, those students who showed no improvement in understanding of the brewing process, regardless of level of motivation, still retained their brewing difficulties two months after the brewing course was complete.

5.1.7 Research Question 6

What were students' attitudes and motivational levels like during the brewing practical?

Students' attitudinal levels, confidence levels, commitment levels and motivational levels were recorded during the brewing practical. Based on the results obtained, students were classified in to three groups namely i) students that showed interest in the brewing practical and thus portrayed improved conceptual understanding of the brewing process *(students B, D & K)*; ii) pupils that showed interest in the brewing practical but did not reveal an enhanced understanding of the brewing process *(students G, H & J)*; and iii) learners that did not show interest in the brewing practical and therefore did not show a developed understanding of the brewing process (*students A, C, E, & I*).

Student B had an observational score of 41, whereas students D & K had scores of 39 as shown in fig. 12. This is because during the brewing practical, students B, D & K showed high confidence levels, their interest and commitment levels were high and their attitudinal levels were also high. To be exact, these students made an effort to learn from the practical- they were participative, interactive and worked hard. On the other hand, as illustrated in fig. 12, student G had an observational score of 27 and those of students H & J were both 25. Interestingly, students G, H & J also had high confidence levels- their interest and commitment levels were high and their attitudinal levels were high. Students A, C, E & I had an observational score of 18 (fig. 12); this is because during the brewing practical, the students' attitudinal, commitment and motivational levels were low. Instead of engaging fully in the exercise, the students played cards, and chatted about "*weekend events*".

5.1.8 Research Question 7

How well did students rate their experiences of the whole TLS?

In their evaluation questionnaire, all the students indicated that the TLS helped improve their understanding and visualization of the brewing process, and also pointed out that they enjoyed the brewing process. Furthermore, they indicated that they i) made an effort to learn from the brewing practical; ii) attempted to solve problems encountered during the practical; and iii) interacted with other students. Based on the researcher's observations, students B, D, K, G, H & J enjoyed the practical, made an effort to learn from the practical, tried to solve problems encountered during the practical and interacted with other students. On the other hand, students A, C, E & I appeared not to enjoy the practical; these students did not make an effort to i) learn from the practical; ii) interact with other students; and iii) solve any problems encountered during the practical. Instead, they played cards and talked about “*weekend events*”.

5.1.9 Research Question 8

How well did students’ motivational levels and their rating of the TLS correlate with any changes in understanding?

Students B, D & K showed high motivational levels (fig. 12) and their ratings of the TLS correlated well with the researcher’s observations. Moreover these students’ conceptual understanding of the brewing process significantly increased during the TLS: the students’ cognitive and visual skills improved during the TLS. It is possible that the students’ active involvement in the practical and the fact that they actually used the micro-brewery apparatus during the brewing practical helped in promoting their conceptual understanding of the brewing process. This is because science education literature has established that models (e.g. the micro-brewing apparatus) are used to improve learning (Chittleborough *et al.*, 2005), explain concepts (e.g. the brewing concepts), processes (e.g. process involved in brewing) and “difficult non-observable” abstract phenomena (Treagust *et al.*, 2002).

In contrast, students G, H & J (fig. 12) also showed high motivational levels during the TLS, their evaluations of the brewing TLS correlated with the researcher’s observations. However, these students’ conceptual understanding of the brewing process did not improve: their cognitive and visual skills did not develop during the TLS. For this reason, it can be suggested that high motivation levels do not guarantee learning. On the other hand, student A, C, E & I showed low motivational levels (fig. 12) throughout the TLS and their TLS evaluations did not correlate with the researcher's observations. When evaluating the TLS, the students indicated that they enjoyed the practical and made an effort to learn from the practical, however, based on the observational data, the students seemed not to be interested in the practical and they did not make any effort to learn from the practical. For this reason, the students' conceptual understanding of the brewing process did not improve. Therefore, suggestions can be made that low attitudinal, commitment and motivational levels guarantee that learning will not occur.

The correlation between students' science achievement and their attitudes, confidence, interest and motivation in science has been investigated by a number of researchers. For instance, Berg (2005) and Winberg (2006) discovered that chemistry students' positive attitudes towards learning and motivation were key factors for developing their knowledge. Furthermore, Chang and Cheng (2008) discovered there was a positive correlation between senior high school students' science achievement and their confidence and interest levels in science. Therefore, this suggests that motivation is one of the key important factors in attaining improved learning.

5.2 Limitations of the Study

The limitations of this study include the fact that the investigation was restricted only to microbiology students at the University of KwaZulu-Natal with a small sample size (Section 3.3) which precluded generalization of the findings to larger populations of students and at other institutions. As a result, there is a possibility that the results, especially for the brewing difficulties discovered, may or may not be similar to the results that will, in the future be obtained from other institutions. Certainly, further research is required to fully describe the nature of the difficulties at level 4 on the framework. The second limitation is that the study was entirely qualitative, meaning that the researcher was clearly subjective during the interpretation of the results. However this approach and qualitative research design successfully addressed the stated research questions and was therefore the correct mode of research for this study. The third limitation was the fact that students might have learned from the pre-test. However, as stated in section 3.8.1, students were not allowed to keep copies of the pre-test question papers nor were any answers discussed with them prior to the post-test. Fourthly, conducting, transcribing and analyzing interviews was time consuming (Gall *et al.,* 2003).

5.3 Implications of the Study

Based on the results of this study, it was discovered that concepts such as coupling, specific gravity and glycolytic reactions, especially parallel coupling and the roles of co-enzymes in glycolytic reactions, were the major concepts that students had difficulties with. Therefore, the researcher suggests that effective teaching methods should be developed in order to enhance the learning of these concepts. Besides this, the researcher suggests the following should be taken into consideration:

5.3.1 Brewing lectures

Currently, the brewing lectures are all conducted in one week; this in the view of the researcher is a disadvantage because students are not given enough opportunity to i) grasp what they have been taught; and ii) research more on the topic. Therefore, the researcher suggests that the brewing lectures should be conducted over at least two weeks, and include interactive tutorials, in order to give students enough time to process and understand the newly learnt brewing knowledge. Moreover, during the actual brewing lectures, various important formulae were only briefly introduced to the students. For instance, the formula used for calculating the percentage alcohol in beer was briefly introduced to the students and only informed verbally how the formula is used. Instead it is recommended that the students be taught step by step, with the aid of examples, how the formula is used to calculate alcohol percentage v/v and w/w. This will assist the students to understand the formula and how to use it instead of just rote learning the formula for tests.

The lecture notes, especially those outlining the various brewing stages, are also not presented in the sequence in which the steps occur during the brewing process. This, at first, confused the students because they were unsure of the order in which the stages occurred during the brewing process. It was only during the brewing practical that they were enlightened regarding the order of occurrence of the brewing stages. Thus, the researcher recommends the lecture notes are changed accordingly. Moreover, although the students studied the metabolism course at undergraduate level, the researcher feels it would be beneficial to include the teaching of the glycolytic pathway, as well as other relevant yeast metabolism, to students in this course so as to remind them about these key processes.

5.3.2 Brewing Practical

There were ten students in total and they were divided into two groups consisting of five students with each group being informed to brew a beer of their choice. During the brewing days, the researcher observed that, within each group, there were students that worked throughout the practical, those that told other students what to do and those that just observed what the other students were doing. As a result, some students did not learn from the brewing practical. To try and alleviate this problem, the researcher recommends that the students should be divided into five groups of two students each, which may encourage them to share the work more equally. Moreover, during the brewing practical, all the groups were made to brew on the same day. This is tiring and de-motivating especially for the group that brews last because brewing is a long process. To minimize this problem, the researcher recommends that each group brews on a separate day. This will enable each group to start brewing in the morning while they are still energetic and enthusiastic and thus will increase the chances of students learning from the practical. As stated, some students appeared not to be interested in the brewing practical, and there is a possibility that this might have been caused by the tiring long hours that the students had to wait before they could start brewing.

During the practical, the researcher noticed that the demonstrator remained mainly isolated from the students and left before the brewing practical sessions were completed. This is a disadvantage because the students were observably de-motivated by this, especially when they realized that someone who is supposed to help them is not interested in their work. To alleviate this problem, the researcher recommends that the demonstrators are specifically briefed regarding the expectations of the job and trained in various interactive techniques that will facilitate active learning among the students. More specifically, they ought to be encouraged to i) be available throughout the practical; ii) to motivate and encourage students to ask questions and interact with other students; iii) monitor the students progress and ensure that they understand what they are doing; and iv) ensure that all students participate in every aspect of the practical.

With regards to the micro-brewing apparatus, the researcher thinks there should be labels on the different parts of the apparatus, especially on the in-let and out-let valves. This, according to the researcher will aid the students to know which valves to close and open at particular intervals, thus will prevent groups from accidentally flushing out their wort (as some students did during the practical).

5.4 Future Research

Although the current study has built a foundation for the effectiveness of the TLS, based on the micro-brewery apparatus, the researcher feels there is an important need to extend this study in a manner ascribed below:

1. **Students' conceptual understanding of the brewing process:** there is a need to further probe students' understanding of the brewing process, that is, their ability to use cognitive and visual skills to explain brewing phenomena. More activities that test for students' understanding and ways of reasoning should be included in the TLS. Such activities could include group presentations (two people per group) in which students will be given different brewing topics to present on.

2. **Student difficulties and alternative conceptions:** there is a need to probe deeper into the nature of brewing difficulties and alternative conceptions that students hold in connection with the brewing process. It is also important to further identify the major concepts that students have difficulties with and classify them at level 4 on the framework.

3. **Students' reasoning and problem solving skills:** so far, we have only concentrated on the effectiveness of the TLS in developing students' conceptual understanding of the brewing process. However, since understanding also involves the ability to reason with and use prior knowledge to solve problems, there is a need to investigate the efficacy of the brewing TLS in promoting students' problem solving skills. This will enable us to devise a thinking strategy that novices use when solving problems. However, it is crucial to ensure that students are tested for their understanding of how the formulae are applied, rather than their ability to memorize the formulae and mindlessly apply algorithms.

4. **Conducting a larger study and in other institutions:** the usefulness of the brewing TLS in developing students' understanding of the brewing process has only been investigated on microbiology honours students at UKZNP. Therefore, there is a need to conduct this study in other institutions in order to determine if the current research findings are applicable to other institutions. There is also a need to extend this study to larger student samples to enable the generalizability of the findings to a broader population so that other institutions that teach brewing can also benefit from this work.

5.5 Conclusion

The study was able to address all the research questions and therefore built a foundation for the efficacy of the brewing TLS in a microbiology brewing course. However, further studies need to be conducted in order to substantiate the importance of using the brewing TLS to teach brewing microbiology.

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Appendix 1

Informed Consent Document: Microbiology Honours Students

Project Title: Microbiology Honours Students' Conceptual Development during a Beer Brewing Teaching Learning Sequence (TLS)

Research Questions:
The above title will be addressed by the following research questions:

1. What concepts are essential for understanding the process of beer brewing?
2. Did those students with sound conceptions develop deeper understanding during TLS?
3. Did students show any conceptual difficulties with the brewing concepts?
4. Did any remediation of such difficulties occur during the TLS?
5. Did students show retention of (mis)understanding two months after the brewing practical?
6. What were students' attitudes and motivational levels like during the brewing practical?
7. How well did students rate their experiences of the whole TLS?
8. How well did students' motivational levels and their rating of the TLS correlate with any changes in understanding?

Masters Student: Ms Rethabile Tekane (Tel. 033 260 5429; 084 574 7956)

Project Supervisors (School of Biochemistry, Genetics and Microbiology):
Prof. Trevor Anderson: Biochemistry & Science Education Research Group; Tel. 033 260 5464; 083 636 7770
Mr. Charles Hunter: Microbiology; Tel. 033 260 5528; 084 812 9967

Dear Microbiology Honours students,
We would greatly appreciate your participation in the above project which will integrate seamlessly into the micro-brewery project that you will be doing as part of the requirements for your honours degree. The expectations of participants and potential benefits to be derived from participating, that are over and above the normal course requirements, are listed below.

Expectations of participants:
The following data will be collected during and after your micro brewing project and used to write a thesis and various potential publications:

- Written data in the form of one pre-test and one post-test;
- Observational data recorded informally by the Masters student;
- Verbal data from informal interactions with the Masters student;
- A maximum of two one-on-one interviews that will be audio taped.

Potential Benefits:

- You stand to gain a deeper understanding of the brewing process and the important concepts and parameters of relevance to this process;
- You should improve your problem-solving and visualization skills not only in brewing but in science in general;
- Findings of the research will be used to improve the microbrewery project both for you and for future groups of Microbiology Honours students.

Conditions of participation:

- Your name will not be divulged in any written report, thesis or publication using the data collected from this project;
- The source of the data will be treated in a sensitive and confidential manner;
- Participation in this research is voluntary; participants have the right to withdraw at any point of the study, for any reason, and without any prejudice, and the information collected and records and reports written regarding that participant will be discarded;
- Participant will receive the sum of R 100 for participation in formal and informal interviews.

DECLARATION

I……………………………………………………………… (Full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project. I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIANT: DATE:

Appendix 2

Name…………....………Company……………………………Email:………..(Optional)

Brewing experience: Industrial brewer…...Micro-brewer...….Home brewer….
Educationist…..... Student……

Please rate the following list of concepts and parameters in terms of their importance for <u>mastering</u> the brewing process. Include any additional concepts in the space provided at the end of the questionnaire.

Brewing Concepts and Parameters	Response (Please mark with a X)		
	Important	**Not important**	**Undecided**
Raw Materials Stage: A brewer has to understand the following:			
▪ Different raw materials involved in brewing			
▪ Different enzymes present in raw materials involved in brewing			
▪ Different microbial contamination present in raw materials involved in brewing			
Mashing Stage: A brewer has to understand the following:			
▪ Different enzymes involved in mashing			
▪ Effect of pH			
▪ Effect of temperature			
▪ Effect of water quality			
▪ Importance of Calcium in the mashing process			
▪ Importance of sanitation			
Lauter stage: A brewer has to understand the following:			
▪ Effect of the temperature of sparging water on wort			
▪ Effect of the pH of sparging water on wort			
▪ Effect of oxygenation			
▪ Measurement of the specific gravity			
▪ Importance of sanitation			

Wort boiling (kettle): A brewer has to understand the following:			
▪ Effect of temperature			
▪ Effect of hop addition (time at which it is added) on wort flavour and aroma			
▪ Effect of pH in wort boiling			
▪ Effect of whirl-pooling wort			
▪ Effect of cold break on wort			
Fermentation: A brewer has to understand the following:			
▪ Effect of temperature on fermenting wort			
▪ Effect of wort aeration before fermentation			
▪ Effect of pitching rates of yeast on fermenting wort			
▪ Effect of different strains of yeast on the fermenting process			
▪ Effect of fermentor vessel sanitation			
▪ Duration of fermentation			
▪ Coupling processes in glycolysis			
▪ Importance of stoichiometry			
Other brewing concepts (Please specify and rate importance):			

Appendix 3

Student No. ……………………………………………………………………19 March 2010

Brewing 101 (Microbiology 721): Test Number 1

Answer the following questions, on separate paper. The test counts for marks, 15 marks per question, so it is in your interests to give full but concise answers.

<u>Previous modules completed (please tick):</u>

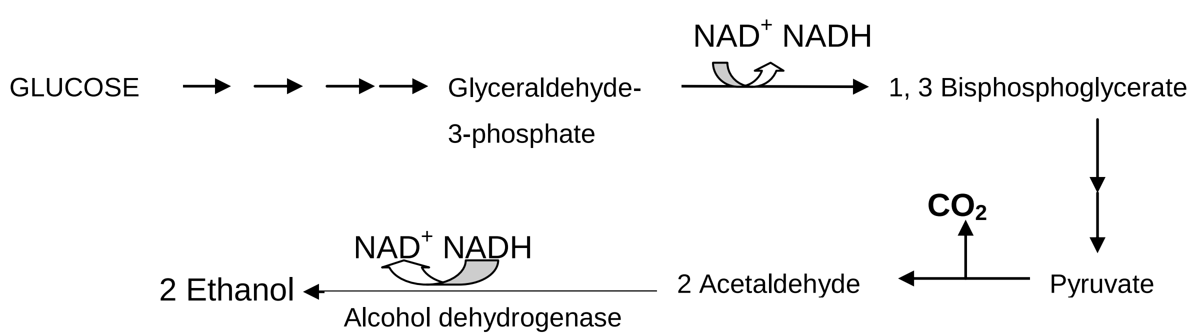
Year of study	**Modules**	
	Biochemistry	**Microbiology**
2nd year	• Bioc 201 • Bioc 212	• Micro 213 • Micro 214
3rd year	• Bioc 310	• Micro 320 • Micro 304 • Micro 360

1) Brewing is a process consisting of several steps and stages.

   a) Draw an annotated diagram of the various steps in the overall process of brewing

   b) Use your diagram to explain each step in the brewing process

2) During fermentation, yeast converts glucose to ethanol and carbon-dioxide is given off, as shown below:



a) Consider the fermentation process depicted above. Predict what effect the following will have on ethanol production :

   i) If NADH and NAD^+ are absent?

   ii) Would ethanol production continue if NAD^+ was present?

   iii) Give reason(s) for your answers in (i) and (ii);

b) If alcohol dehydrogenase is totally inhibited by a toxic substance?

   i) Give reason(s) for your answer;

c) If the culture is vigorously aerated?

3) Consider a situation in which a brewer forgets to whirl-pool the wort before pitching and answer the following questions:

   a) What effect will this have on the brewing process?

   b) Give reason (s) for answer

4) Wort boiling is one of the most important steps in brewing:

   a) List the major processes which occur during wort boiling that contribute to the flavour and colour of the final product
   b) Explain each process and indicate their importance for brewing.

5) After 12 hours of adding fresh yeast to the cooled wort, a home brewer noticed that fermentation still had not started. Based on your knowledge of the brewing process, answer the following questions:

   a) What did the brewer observe that led him/her to decide that the wort was not fermenting?

   b) Suggest **five** possible causes of the problem;

c) Suggest how the brewer might, in the future, prevent the problem from occurring.

6) Consider the supplied fermentation profile graphs (fig. 1 & 2 below) and answer the following questions:

a) Explain the relative trends shown in figure 1

b) Based on the graphs in figure 1and 2;

i) What do the final S.G. readings represent?

ii) What is the impact of the final S.G. on the brewed product?

c) Use the information provided in figures 1 & 2 to explain why the lager took longer to ferment than the ale.

7) Teams **A** and **B** were involved in a brewing competition. The teams used the same sources and amounts of water, hops, yeast and malted barley. However, team **A** produced **fruity, full-bodied ale,** whereas team **B** produced **thin, watery and hazy lager**. Use your knowledge of the brewing process to answer the following questions:

a) **Explain** how the two teams were able to produce different types (**lager** and **ale**) of beer even though the same sources and amounts of ingredients were used.

b) Explain what brewing conditions led to the production of:

i) Thin and watery beer
ii) Full bodied beer
iii) Fruity beer

c) Explain what the brewer could do in the future to avoid the formation of haze in beer.

8) It is known that during fermentation, $C_6H_{12}O_6$ is converted into two molecules each of CH_3CH_2OH and CO_2. This means that for every molecule of CO_2 given off, one molecule of CH_3CH_2OH is produced. Consider the situation in which Hansa pilsner has an OG of 1.04 and a FG of 1.01. If the difference between the two gravities is

directly related to the amount of CO_2 given off, calculate the alcohol percentage (v/v) present in Hansa Pilsner:

(**Molecular weights**: $C_6H_{12}O_6$= 180.156, CH_3CH_2OH= 46.0688, CO_2= 44.0098, Density (D) of alcohol = 0.79kg/l)

9) Use all the concepts provided below to construct a concept map for the brewing process;

yeast, pH, proteins, amino-acids, caramelization, hops, isomerization, wort-boiling, barley, proteolysis, enzymes, whirl-pooling, sterilization, polyphenols, mashing, temperature, starch, ethanol, glucose, glycolysis, fermentation, aeration, and coupling, specific gravity, time

Use for answering Question 6

A TYPICAL ALE FERMENTATION PROFILE

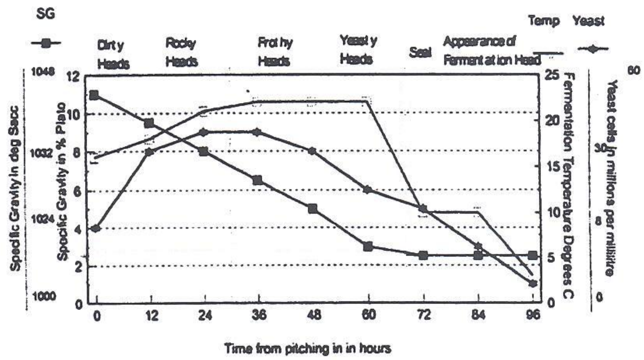


Figure 1

A TYPICAL LAGER FERMENTATION PROFILE

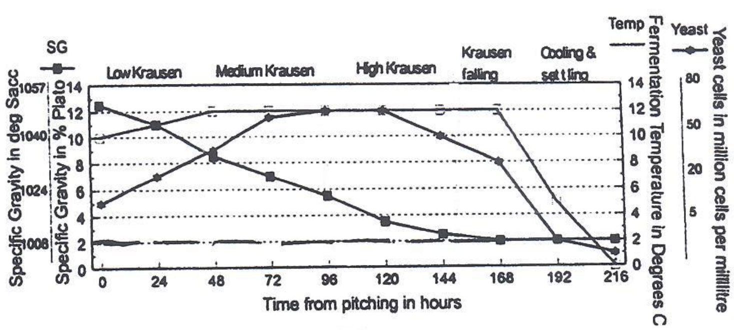


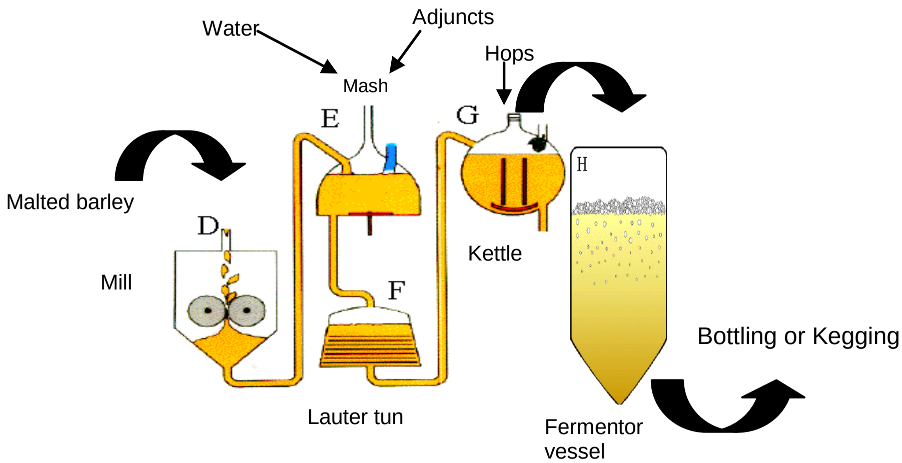
Figure 2

Appendix 4

Brewing concepts	Questions												
	No. 1	**No. 2**			**No. 3**	**No. 4**	**No. 5**			**No. 6**	**No. 7**	**No. 8**	**No. 9**
	a & b	**a**	**b**	**c**	**a & b**	**a & b**	**a**	**b**	**c**	**a, b & c**	**a, b, & c**		
Substrates	x	x	x					x			x		x
Enzymes	x	x	x					x		x	x		x
Ph	x					x							x
Temperature	x				x	x		x	x	x	x		x
Time	x									x	x		x
Sanitation	x												
Water Quality	x										x		
Process e.g. Mashing	x	x		x	x	x	x	x	x	x	x	x	x
Specific Gravity	x						x			x		x	x
Solubility	x				x	x							x
Sterility						x							x
Stoichiometry							x				x	x	
Coupling		x	x		x								
Contamination	x										x		x
Precipitation	x				x	x							x
Oxygenation	x							x	x				x
Caramelization	x					x							x
Isomerization	x					x							x
Products	x						x						x
Ingredients	x				x	x	x	x	x	x			x

Appendix 5

Table 16: Propositional Statements

Questions	Propositional statements
Question 1(a).	
Question 1(b).	**The following stages are involved in brewing:** **Milling** • Done in order to crush barley into smaller particles and to expose starch through breaking the endosperm. • Important to ensure that the husk is kept intact because it is used as a filtering material in lautering. **Mashing** • The milled barley is mixed with water and then mashed at different temperatures depending on the required beer style. • Various enzymes are activated; alpha and beta amylases, peptidases, glucanases, dextrinases, and saccharases. • Alpha amylases have optimum temperatures at 65-70°C and optimum pH at 5.5-5.8. • Alpha amylases act on the alpha-1,4 bonds and degrade starch into dextrins, non- fermentable sugars. • Beta amylases on the other hand have optimum temperatures at 57-65°C and optimum pH at 5.4-5.6. • Beta amylases act on the alpha-1,4 glycosidic bond at the non reducing end of starch producing maltose, a fermentable sugar. • Peptidases are activated at temperatures in the range of 40-60°C and have optimum pH in the range of 4.8-8.8.

	• Peptidases hydrolyse proteins to amino-acids; amino acids are crucial for yeast growth and metabolism. • Protein degradation products contribute towards fermentation, beer flavour and colour, palate fullness and beer foam. • Glucanases have optimum temperatures ranging from 40-70°C and have optimum pH ranging from 4.5-7.0. • Glucanases degrade cell wall components into beta glucans with low and high molecular weight and beta glucanes. • Cell wall modification is important because it minimizes haze and beer filtration problems. • Three processes occur during mashing; gelatinization, liquefaction and saccharification. • Gelatinization occurs when starch absorbs a large amount of water, swell, burst, and form a viscous solution. This sets free the starch molecules hence, they are more easily attacked by enzymes. • In liquefaction alpha-amylase breaks down amylose and amylopectin into small chains, thus decreasing the viscosity of the gelatinized starch. • During saccharification, alpha-amylases continue to break down starch into dextrins, non-fermentable sugars; βeta-amylases degrade starch into maltose, fermentable sugars; limit dextrinases break down the 1,6 bonds in starch into dextrins, non-fermentable sugars; and maltases degrade maltose into glucose. **Lautering** • Done so as to separate wort from spent grains. • Spent grains and husk are used as filtering materials. • Mash is transferred to the lauter tun where filtration of the wort occurs. • Once the first wort has been drained, spent grains are sparged in order to wash out more wort. • It is important to stop sparging before the specific gravity becomes too low; this is done to avoid the leaching out of polyphenols which contribute to the formation of haze in beer. • It is important to ensure that: sparging water is warm and not hot; hot water results in the leaching of undesirable polyphenols and silicates. Polyphenols form complexes with proteins which later contribute to the formation of beer haze. • Make sure that water used for sparging is soft; hard water contains carbonates and bicarbonates which act as weak bases and raise the pH of sparges. High pH results in the draining of polyphenols which contribute to the formation of

beer haze.

Wort boiling

The following processes occur during boiling: sterilization, inactivation of malt enzymes, isomerization of hop components, caramelization of sugars, Denaturation and coagulation of proteins, acidification of wort, and volatilization of DMS.

***Sterilization*;**

- Unboiled wort contains micro-organisms which can affect the flavour and taste of the final product. Therefore to avoid this, wort is boiled at 102-103°C in order to kill the micro-organisms.

Inactivation of malt enzymes;

- It is possible that the lautered wort still has amylolytic enzymes. If these enzymes are allowed to pass into the fermentor vessel, they would cause amylosis hence, resulting in the production of dry beer with low nutritional value. Therefore, wort boiling destroys all malt enzymes that might still be present in the wort.

Isomerization of hop components:

Two types of hops are added during boiling; bitter hops added at the beginning of the boil; and aromatic hops added 10-15 minutes before boiling is stopped. During boiling, α-acids are isomerized to iso- α-acids which give bitterness to beer. Aromatic hops contain highly volatile oils for this reason they are added 10-15 minutes towards the end of the boil in order to retain the aroma.

Caramelization of sugars;

- Browning reactions occur between reducing sugars and amino acids via Schiff bases to ketoses. The ketoses decompose to reductones which react with amino acids to form aldehydes which have characteristic flavours. Furthermore, aldehydes react with amino acids to produce melanoidins which increase the colour of the wort.

Denaturation and coagulation of proteins;

- Proteins are denatured at high temperatures.
- During boiling whirl-pooling takes place; whirl-pooling encourages hot break.
- During hot break, the denatured proteins are coagulated and settled at the bottom of the kettle.
- This is important because the clarity of beer is improved.

Acidification of wort:

- Calcium present in brewing liquor reacts with phosphates from the malt to from calcium phosphate. During boiling, calcium phosphate precipitates and this lowers the pH of the wort. Furthermore, pH is lowered as a result of the formation of melanoidins and addition of hop acids. Low wort pH is favoured because: most spoilage micro-organisms do not tolerate acidic conditions.

Volatilization of unwanted DMS:

- S-methyl methionine (SMM) is a precursor of dimethylsulphide (DMS) and it is formed during malting. DMS is not favoured in brewing because it gives beer a corn like smell and taste. However, during boiling, SMM is converted to DMS which is highly volatile thus it evaporates.

Whirl-pooling

- Aim is to encourage cold and hot breaks, to settle out hop debris and to improve flavour and clarity of the final product.
- During cold break, protein polyphenol complexes lose their solubility at cooler temperatures and precipitate.
- During hot break proteins are coagulated.
- The coagulated proteins and trub are settled into a cone at the bottom of the kettle.

Wort cooling

- Wort is cooled to temperatures below 10°C.
- Heat exchangers in the form of plates or pipes are used to cool down the wort: water is used as a cooling medium.
- Wort cooling is important because yeast can grow and metabolize at low temperatures.

Fermentation

- Yeast growth occurs during the first few hours of fermentation. This is necessary in order to ensure that there is enough yeast to convert fermentable sugars to ethanol and carbon-dioxide.
- During fermentation, glucose is converted to ethanol and carbon-dioxide.
- Temperature used in fermentation depends on the type of yeast used.
- Top fermenting yeasts are active at 10-20ºC and take 5-6 days to complete fermentation.
- Bottom fermenting yeasts are active at 5-10ºC and ferment for 7-12 days.
- During fermentation, pH decreases. This is essential because: precipitation of colloidal unstable protein polyphenol complexes is accelerated; beer taste is refined; and foam stability is increased.

	Maturation • Aim is to remove excess yeast and haze forming protein polyphenol complexes. • During maturation, beer is stored at low temperatures (-2ºC), filtered and carbonated. • Storing beer at very low temperatures encourages the formation and precipitation of protein polyphenol complexes. • Precipitation of these complexes leads to the formation of chill haze, thus beer is filtered at low temperatures in order to remove the haze. • Maturation aids in flavour development, and removal of undesirable flavours.
Question 2 (a)	
(i)	In the absence of NADH and NAD^+, ethanol will not be produced.
(ii)	Ethanol production will continue in the presence of NAD^+.
(ii)	• Reduction of NAD^+ to NADH is coupled in parallel with the conversion of glyceraldehydes-3-phosphate to 1,3 bisphosphate. • The two reactions depend on one another, that is, one reaction cannot occur in the absence of another reaction. • Likewise oxidation of NADH to NAD^+ is coupled in parallel with the conversion of acetaldehyde to ethanol. Since the two reactions depend on each other, one reaction cannot occur in the absence of another reaction. • NAD^+ (co-substrate) and glyceraldehyde-3-phosphate (substrate) are needed for the production of 1,3 bisphosphate whereas, NADH (co-substrate) and acetaldehyde (substrate) are utilized for the production of ethanol. • Therefore, if NAD^+ and NADH are absent, then ethanol will not be produced. • However, if only NAD^+ is present, the production of ethanol will occur, the reason being, NAD^+ will be reduced to NADH. • NADH is used as a co-substrate involved in the production of ethanol.
Question 2 (b)	
(i)	Ethanol production will continue in the presence of NAD^+.
(ii).	• Alcohol dehydrogenase (**E**) does not only catalyze the conversion of acetaldehyde to ethanol, instead, this enzyme is also involved in the actual conversion of acetaldehyde to ethanol because: • It provides the active site for the binding of the substrates (**S**) (NADH and acetaldehyde) of the reaction to form a short-lived enzyme-substrate complex

	(**ES**) as shown below: $$\mathbf{E + S \rightleftharpoons E \longrightarrow E + P}$$ • During the transition state, the substrate is converted in to the product which dissociates from the enzyme. • However, in the presence of an inhibitor, the inhibitor binds to the active site of the enzyme and thus prevents the substrate from binding to the active site. Therefore, no products will be formed as shown below: $$\mathbf{E\ +\ \rightleftharpoons EI \not\longrightarrow E + P}$$ • Therefore, in this case, the toxic substance will bind to the active site of alcohol dehydrogenase and thus prevent the binding of NADH and acetaldehyde. • Due to this, an enzyme-substrate complex will not be formed; hence ethanol will not be produced.
Question 2(c).	• Once aerated, pyruvate is converted to Acetyl-CoA via a decarboxylation process catalyzed by pyruvate decarboxylase. • Acetyl-CoA enters the Krebs cycle where it is fully oxidized to CO_2 and H_2 O. • Energy liberated is used in ATP synthesis, a process referred to as oxidative phosphorylation. • Since ethanol production occurs under anaerobic conditions, ethanol will not be formed under aerobic conditions.
Question 3(a).	• Unwanted compounds/materials such as hop trub and coagulated proteins will be transferred to the fermentor. • These will affect or influence yeast activity, the flavour, aroma and clarity of beer.
Question 3(b).	• Whirl-pooling encourages cold and hot breaks. • Hot break involves the coagulation of proteins, whereas cold break involves the precipitation of protein-polyphenol complexes that lose solubility at cooler temperatures. • Protein-polyphenol complexes cause the formation of haze in beer, therefore precipitating the complexes aids in improving beer clarity. • Whirl-pooling also settles the coagulated proteins at the bottom of the kettle. This also improves beer clarity. • Therefore, if the brewer forgets to whirl-pool, the flavour, aroma and clarity of beer will be affected. Yeast metabolism will also be affected; yeast might

	metabolize the unwanted protein material thus result in off-flavours.
Question 4(a).	• Caramelization • Isomerization • Denaturation of and coagulation of proteins • Volatilization of volatile substances • Sterilization of wort • Acidification of wort
Question 4(b).	***Caramelization*** • Browning reactions occur between reducing sugars and amino acids via Schiff bases to ketones. • Ketones decompose to reductones which react with amino acids to form aldehydes which have characteristic flavours. • Aldehydes react with amino acids and produce melanoidins which give colour to the wort. • Hence the wort develops a darker colour during boiling. ***Isomerization*** • Bitter hops contain a high proportion of alpha-acids, these alpha acids are insoluble in cold wort. • So, during boiling, alpha acids are isomerized into iso-alpha acids and these are soluble in wort. • Iso-alpha acids are bittering substances, hence they add bitterness to the final product, beer. ***Denaturation and coagulation of proteins*** • Proteins are denatured by high temperatures. • During wort boiling, whirl-pooling also takes place; whirl-pooling encourages hot break. • During hot break, the denatured proteins are coagulated and settled at the bottom of the kettle. • This is important because protein polyphenol complexes are not formed, hence reducing formation of haze in beer. ***Volatilization of DMS*** • S-methyl methionine (SMM) is a precursor of dimethylsufide (DMS). • DMS is not favoured because it gives beer a corn like smell and taste. • During boiling, SMM is converted to DMS.

	• DMS is highly volatile, hence it evaporates. ***Sterilization of wort*** • Unboiled wort contains micro-organisms which can affect the activity of yeast, flavour and taste of the final product. • Boiling at high temperatures (102-103°C) kills such micro-organisms. ***Acidification of wort*** • Calcium present in brewing liquor reacts with phosphates from the malt to from calcium phosphate. • During boiling, calcium phosphate precipitates and this lowers the pH of the wort. • Furthermore, pH is lowered as a result of the formation of melanoidins and addition of hop acids. • Low wort pH is favoured because: most spoilage micro-organisms do not tolerate acidic conditions; and it encourages precipitation of protein polyphenols complexes.
Question 5(a).	• During fermentation glucose is converted to ethanol (alcohol) and carbon-dioxide as shown below: $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$ ***Kunze, (1999)*** • Carbon-dioxide is a soluble gas, thus its release is symbolized by the production of bubbles. • If no bubbles are observed from either the wort or gas outlet, then it's a sign that fermentation is not occurring. • Specific gravity is a measure of the amount of solute (sugar) in solution. • During fermentation as sugars are converted to ethanol, specific gravity decreases due to a decrease in the amount of solute (sugars) in solution. • Therefore, if specific gravity after the 12 days has not decreased, then this shows that fermentation is not occurring.
Question 5(b).	***Old yeast strains*** • Yeast cells require nutrients for growth and metabolism.

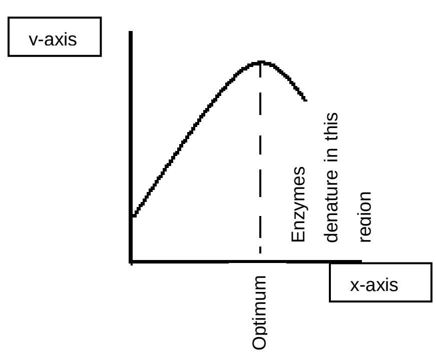
- Nutrients enter yeast cells through their cell membranes via either facillated diffusion or osmosis.
- Old yeast cells have weak cell membranes that are highly prone to autolysis/breaking.
- Using old yeast strains might prevent the occurrence of fermentation as old cells are not able to uptake nutrients required for growth and metabolism.
- Old yeast cells might have lost vigour and vitality.

Oxygen deficiency

- During the early stages of fermentation, yeast cells use oxygen for the synthesis of sterols.
- Sterols are used for synthesizing yeast cell membranes.
- Cell membranes are required for the uptake of nutrients into yeast cells.
- Yeasts require nutrients for growth and metabolism.
- Therefore if oxygen is deficient, yeast growth will not occur, thus fermentation will be limited.

High pitching temperatures

- Yeast cells function best (grow and metabolize) at optimum temperatures and stop functioning if temperatures are raised above optima. This is because yeast cells contain enzymes that catalyze and are involved in their biochemical reactions.
- Enzymes function within specified temperature range: they function best at optimum temperature, and denature at temperatures above optima as shown below:



- Therefore, if pitching temperature is higher than the yeast's optimum temperatures (± 20°C), then the yeast enzymes will denature.

	Low fermentation temperatures • Different yeast strains work best at different fermentation temperatures. • Yeast used for lagers works best at temperatures ranging from 5-10°C, whereas yeast used for ales work best at temperatures ranging from 10-20°C. • However, if fermentation temperatures are too low, yeast metabolic activity will be reduced to a point where the yeast will become inactive or dormant.
Question 5(c).	• Check the vitality (ability of yeast to perform during fermentation) of yeast. There are many ways used to check for yeast vitality, however, most brewing industries use the acidification power test which involves measuring the change in pH of i) Analar distilled water in which yeast has been suspended and ii) a known concentration of glucose when added to the suspended yeast. The sum of the two pH values gives the acidification power number which indicates the plasma membrane trans-membrane potential of the yeast. • It is important to check for the viability of yeast cells one or two days prior to brewing. This can be done by inoculating the yeast cells in a liquid medium favourable to rapid activation and propagation of yeast cells. When added to a liquid medium, viable yeast cells will be activated and thus propagate. This is often followed by performing a viability test in which the number of viable cells is divided by the total number of cells and the calculated value is presented as a percentage. A microscope is used for counting the yeast cells. • Use suitable pitching temperatures. • Use suitable fermentation temperatures; this will depend on the type of beer being brewed. • Add sufficient oxygen when cooling the wort.
Question 6(a).	• Specific gravity is decreasing steadily and this indicates that fermentation is taking place. • As mentioned, specific gravity is a measure of the amount of solutes in solution, therefore, as the amount of sugars present in the wort decreases (due to fermentation), the specific gravity also decreases. This occurs till it (specific gravity) stabilizes at ± 1.012 (1012 deg/Sacc). • Between 0-12hrs, yeast cells were in the exponential phase hence they increased from 9 million cells to 17 million cells (double the population size). Furthermore, at ± 36hrs, the cells reached a peak of 19 million cells per millilitre, however the cells started to decrease around ± 40hrs because they were flocculating. • Temperature increase is observed during the first 24 hrs of fermentation, and this is due to the kinetic energy produced during the lag phase. After this phase, the temperature remains constant at ± 21°C; the temperature had to be

	kept around 21°C because at temperatures higher than this, yeast metabolism starts producing unwanted flavours. The temperature was controlled by the brewer. However, after 64 hrs, the specific gravity stabiles, therefore the temperature is decreased by the brewer in order to allow yeast to flocculate.
Question 6b (i).	• Specific gravity is a measure of the amount of solutes (sugars) in solution. • As fermentation occurs, the amount of fermentable sugars decreases; specific gravity also decreases. • A decrease in specific gravity occurs till all fermentable sugars are fermented. • Thus the final specific gravity signifies the amount of non-fermentable sugars present in solution after fermentation.
Question 6b (ii).	• The final specific gravity has an impact on the final product. • If the final specific gravity is low, then this means that the amount of non fermentable sugars present in the final product is low. Therefore, the final product will have a i) low carbohydrate content, ii) thin body and iii) high alcohol percentage. • However, if the final specific gravity is high, then this means that the amount of non fermentable sugars present in the final product is high. As a result, the final product will have a i) high carbohydrate content, ii) full body and iii) low alcohol content.
Question 6(c).	• At the start of fermentation, temperatures were low ± 10°C (for the lager, fig. 2) and due to this; yeast took ± 72 hrs to grow. • Furthermore as fermentation progressed, temperature increased to 12°C. Since this temperature is still low, metabolism of yeast occurred at lower rates. • It must be remembered that metabolism of yeast is controlled by enzymes, and temperature is one factor that controls the activity of enzymes. At low temperatures, the activity of enzymes is low, thus in this case, the low activity of yeast enzymes resulted in decreased metabolic rates. • However, the starting fermentation temperature for ale was ± 16°C (fig 1), and because of this, yeast took only ±12 hrs to grow. • Moreover, the fermentation temperature increased to ± 21°C; as a result, the metabolism of yeast occurred at higher rates. • Therefore, lager took longer to ferment due to its low fermentation temperatures, whereas ale took a shorter period to ferment due to its high fermentation temperatures.
Question 7(a).	• Ale and lager yeasts ferment at different temperatures; • Ales ferment at higher temperatures, usually10-20°C, and thus ferment and mature (5-6 days), faster than lagers.

	• Lagers on the other hand, ferment at lower temperatures, usually 5-10°C, and thus take longer to ferment and mature 7-12 days. • Based on the above information, it can be suggested that the two teams used different fermentation temperatures and time, thus resulting in the production of two different types of beer.
Question 7b (iii).	• Esters are essential aroma compounds usually synthesized via a chemical condensation process as shown below: **R'OH + RCOOH ⟶ RCOOR' + H_2O** *Peddie, (1990)* • However, esters found in beer are not only synthesized via the condensation reaction, instead, they are also formed via a biochemical pathway shown below: **RCOOH + ATP + CoASH ⟶ RCO^-SCoA + AMP + PPi** **RCO^-SCoA + R'OH ⟶ RCOOR' + CoASH** *Peddie, (1990)* • Esters have low threshold levels ranging from 0.2ppm- 20ppm: exceeding these thresholds results in an unpleasant fruity flavours in beer.
Question 7(c)	**The following factors have to be controlled in order to reduce the occurrence of haze in beer:** ***Water quality*** • Composition of water influences the formation of haze in beer; water rich in carbonates and bicarbonates is not good for brewing. • Carbonates and bicarbonates act as weak bases and increase the pH of the mash thus more polyphenols are washed off into the wort during sparging. This is a disadvantage because polyphenols form complexes with proteins; these complexes form haze in beer. • Therefore, before brewing, water should be treated in order to decrease the amounts of carbonates and bicarbonates. ***Temperature of sparging water*** • Using very hot water for sparging leads to the leaching of polyphenols into the wort. • Polyphenols form complexes with proteins and these complexes form haze in beer. • Therefore, the brewer ought to ensure that sparging water is warm and not hot.

	Contamination • Contamination of wort by bacteria can also lead to the formation of haze in beer. • Haze might form as a result of gas produced by bacteria.
Question 8(a).	$C_6H_{12}O_6 = 2(CH_3CH_2OH) + 2(CO_2)$ The above equation suggests that 1 molecule of glucose is converted to 2 molecules of ethanol and carbon-dioxide. Furthermore, when 44.0098g of CO_2 is produced, 46.0688g of ethanol is also produced, if this is the case, how much ethanol is produced if 1g CO_2 is formed? 44.0098g CO_2 = 46.0688g CH_3CH_2OH 1g =? ((1x 46.0688)/ (44.0098)) = **1.05g CH_3CH_2OH** As stated, the difference between OG and FG provides the amount of CO_2 given off, therefore how much CO_2 was given off in this case? OG – FG = CO_2 given off 1,04 – 1.01= **0.03g CO_2** It was calculated that 1.05g CH_3CH_2OH is produced if 1g $CO_2$is formed. So how much CH_3CH_2OH is produced if 0.03g CO_2 is formed? 1g CO_2 = 1.05g CH_3CH_2OH 0.03g =? ((0.03 x 1.05) / (1)) = 0.0315 x 100% = **3.2% (w/w) CH_3CH_2OH** If 3.2% (w/w) CH_3CH_2OH is produced, then how much CH_3CH_2OH is produced v/v? Density = (mass)/ (volume) V = (m)/ (d) = (3.2)/ (0.79) = 4.05 = **4.1% (v/v) CH_3CH_2OH**
Question 9	Check Appendix 7

Appendix 6

Scoring of Concept Maps: adapted from Novak and Gowin, (1984) and Ünlü *et al.*, (2006)

1. **Propositions**: 1/2 point for each meaningful proposition
2. **Similarity of propositions**: 1 point for each proposition similar to the researcher's.
3. **Scientific words** : 1 point for each coherent scientific word used as a linking word
4. **Cross-links**: 1 point for each correct cross-link
5. **Direction of Propositions:** 1/2 point for understanding correctly when the concepts and the linking words forming a proposition are read in the drawn direction.
6. **Examples**: 1 point for an example
7. **Use of all concepts**: 1 point for including all the twenty-five concepts in the map.

Appendix 7

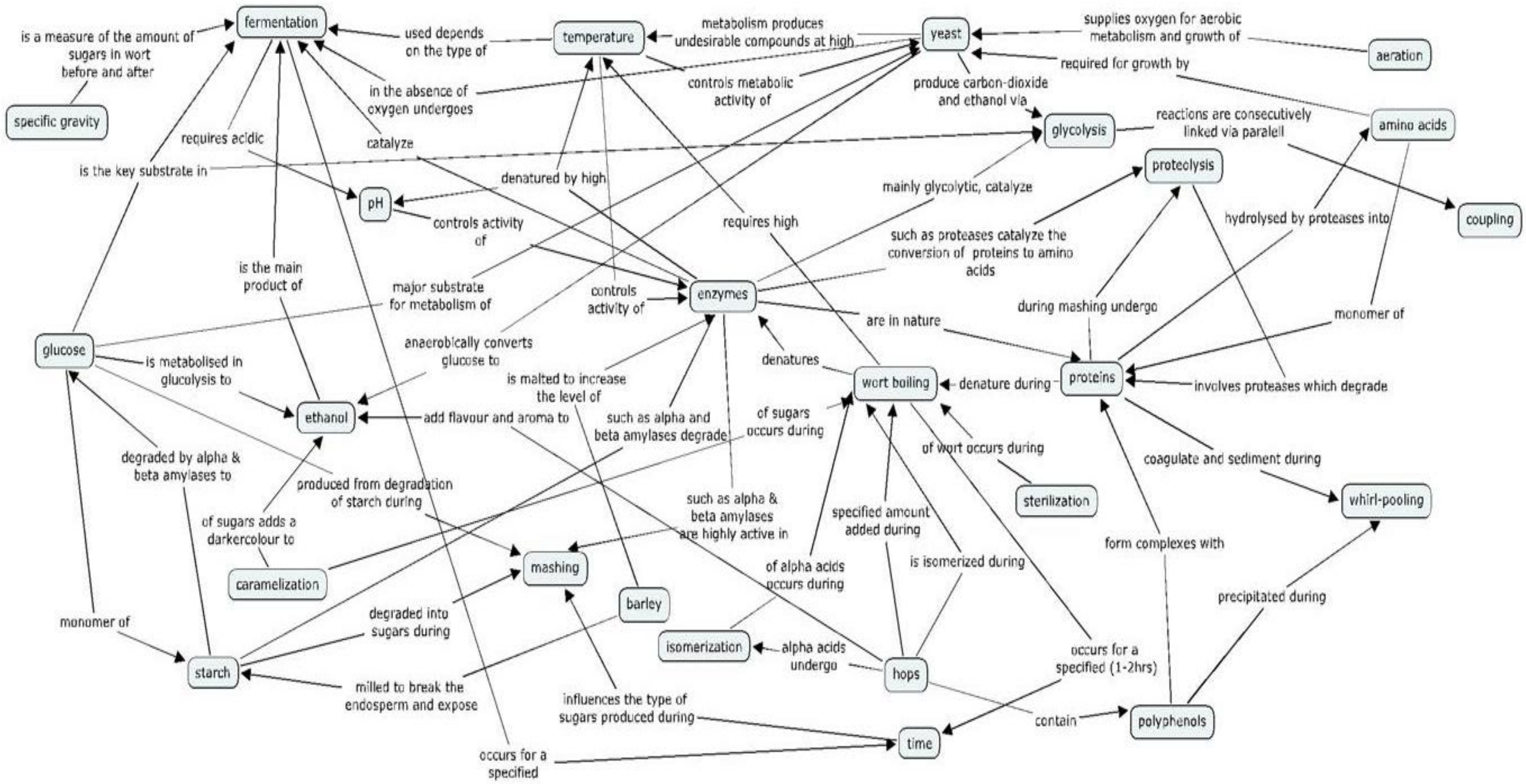


Figure 13: The researcher's concept map.

Appendix 8

1) **Questions asked prior to brewing**

   a) What type of beer have you decided to brew today, explain in terms of body, colour and alcohol content?

   b) So, how do you intend on ensuring that you obtain your expected beer?

   c) Why did you mill your barley?

2) **Questions asked during the mashing process**

   a) Why is it important to mash?

   b) Why did you decide to use this temperature during mashing? (referring to temperatures used by each group)

   c) Does the mashing process impact on the final product? If yes, explain its impact on the final product.

3) **Questions asked during the lautering process**

   a) Why is it important to lauter the wort?

   b) Does the lautering process have any impact on the final product? If yeas, explain its impact on the final product

4) **Questions asked during the boiling process**

   a) Why is it important to boil the wort?

   b) Why is it important to whirl-pool the wort?

5) **Questions asked before the fermentation step**

   a) Why have you decided to ferment the wort at that temperature?

   b) How long are you going to allow your wort to ferment? Why?

c) At the end of fermentation, how are you going to know how much sugars were fermented, what percentage of the sugars was fermentable and non-fermentable?

Appendix 9

Figure 14: The micro-brewery apparatus used for brewing at DMUKZNP.

Appendix 10

Student names	A	B	C	D	E	G	H	I	J	K
Variables to be observed										
1) Confidence levels										
• Confident										
• Anxious										
• Confused										
• Uncertain										
2) Behaviour										
a) Motivation: level of interest										
• How often do they answer questions?										
• How frequent do they volunteer to do a particular task during the practical?										
• How do they interact with other students										
b) Motivation: level of commitment										
• Dedicated to work and find solutions (solutions to problems that might occur during the practical) even when facing difficulties										
• Still shows dedication even when exhausted										
3) Attitude to the micro-brewery exercise and its activities: evaluating the activity with some degree of favour or disfavour										
• Cognitive response: make effort to understand and learn from doing activity										
• Affective response: feels comfortable enjoys working on the micro-brewery										
• Behavioural response: Immediately starts handling the apparatus and organizing the activity- makes clear effort										
4) Level of participation in exercise:										
Doer (gets stuck in and does the work)										

Commentator (Tells others what to do)										
Observer (Stands back and doesn't get involved)										

Appendix 11

Student Number...June 2010

Please complete the following questionnaire, by in each case, ticking ONE of the following options nearest to the statement with which you agree: SA= strongly agree, A=agree, N=neutral.

Brewing practical outcome

		SA	A	N	A	SA	
1.	I gained a lot of new information from the brewing practical	☐	☐	☐	☐	☐	I did not gain any new information from the brewing practical
2.	The brewing practical helped improve my understanding of the brewing process	☐	☐	☐	☐	☐	The brewing practical did not help improve my understanding of the brewing process
3.	Working with the micro-brewery apparatus helped me visualize the brewing process	☐	☐	☐	☐	☐	Working with the micro-brewery apparatus did not help me visualize the brewing process
4.	The brewing practical motivated me to be interested in brewing	☐	☐	☐	☐	☐	The brewing practical did not motivate me to be interested in brewing
5.	During the practical, I feel I improved my ability to solve problems to do with beer brewing	☐	☐	☐	☐	☐	During the practical, I feel I did not improve my ability to solve problems to do with beer brewing

Attitude displayed during the brewing practical

		SA	A	N	A	SA	
1.	I felt confident throughout the brewing practical	☐	☐	☐	☐	☐	I did not feel confident throughout the brewing practical

2.	My confidence levels only started to increase during the brewing practical	☐	☐	☐	☐	☐	My confidence levels did not increase during the brewing practical
3.	I was anxious throughout the brewing practical	☐	☐	☐	☐	☐	I was not nervous throughout the brewing practical
4.	My anxiety levels decreased during the brewing practical	☐	☐	☐	☐	☐	My anxiety levels did not decreased during the brewing practical
5.	I was confused throughout the brewing practical	☐	☐	☐	☐	☐	I was not confused throughout the brewing practical
6.	I became less confused throughout the brewing practical	☐	☐	☐	☐	☐	I became more confused throughout the brewing practical

Interest levels

The brewing practical was:

		SA	A	N	A	SA	
1.	Interesting	☐	☐	☐	☐	☐	Not interesting
2.	Fun	☐	☐	☐	☐	☐	Not fun
3.	Exciting	☐	☐	☐	☐	☐	Not exciting
4.	Enjoyable	☐	☐	☐	☐	☐	Not enjoyable

Participation and Commitment levels

		SA	A	N	A	SA	
1.	I asked for help from my group-mates when I did not understand what was happening	☐	☐	☐	☐	☐	I did not ask for help from my group-mates when I did not understand what was happening

2.	I asked for help from another group when I did not understand what was happening	☐	☐	☐	☐	☐	I did not ask for help from another group when I did not understand what was happening
3.	I tried every possible way to find solutions to any problem we encountered during the practical	☐	☐	☐	☐	☐	I did not attempt to find solutions to any problem we encountered during the practical
4.	I did not lose any hope when I did not understand what was happening	☐	☐	☐	☐	☐	I lost hope when I did not understand what was happening
5.	I carried on with the practical even when I felt exhausted	☐	☐	☐	☐	☐	I took a break when I felt tired

Appendix 12

1. Probing students' conceptual understanding of the brewing process (Phase 1).

   a. From your understanding of the brewing process, what knowledge do you think you ought to know in order to understand brewing and be able to solve any brewing problem?

   b. Match the following brewing processes with the brewing stages under which they occur. Provide explanations for your choices.

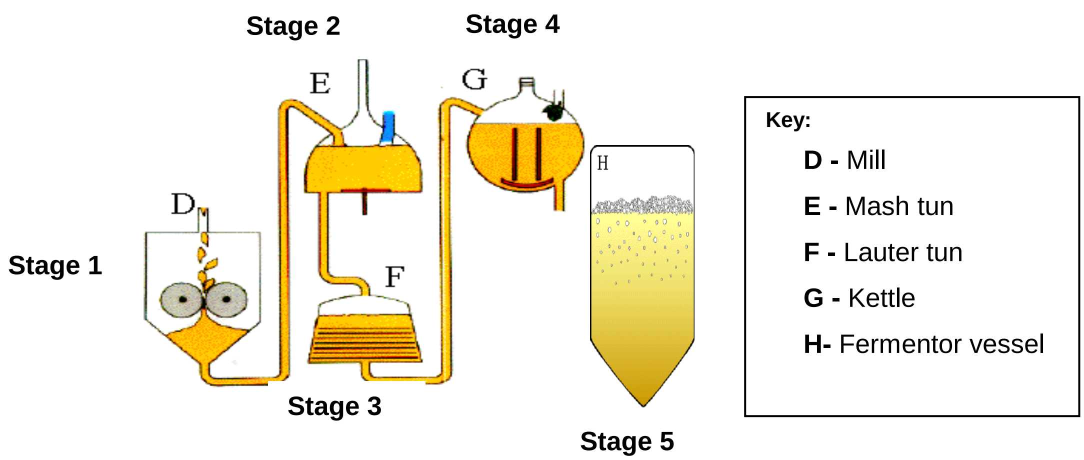
Brewing stages	Brewing processes
• Milling	Protein denaturation
• Mashing	Enzyme activation
• Lautering	Protein coagulation
• Wort boiling	Wort clarification
• Whirl-pooling	Enzyme inactivation
• Wort cooling	Isomerization
• Fermentation	Caramelization
• Maturation	Evaporation of water
• Filtration	Precipitation
• Packaging	

   c. Let's say you are given the following parameters, show how you would calculate the alcohol percentage, and please say out loud what you are doing and tell me the ideas that are running through your mind as you solve this problem;

   OG = 1.030, FG =1.014, Density of alcohol = 0.79kg/l,
   Molecular weights: CO_2 = 44.0098, CH_3CH_2OH = 46.0688

2. Probing students' conceptual understanding of the brewing process after exposure to the diagram (Phase 2).

    a. Use the diagram provided to explain how each stage contributes to the final product.



3. Evaluating student's attitude towards the micro-brewery exercise (Phase 3)
    a. How did you find the brewing practical?
    b. Explain your answer above (asked based on the type of answer provided above)
    c. Did you prepare yourself for the practical?
    d. If "YES", briefly outline what you did to organize yourself for the practical
    e. If "NO" why did you not prepare yourself for the practical?
    f. Did you learn anything from the practical?
    g. If "YES", please specify what you learnt
    h. From your point of view, do you think there were any particular factors that facilitated your learning?
    i. From your point of view, do you think there were any particular factors that made it difficult for you to learn anything from the practical?
    j. If you were given a second chance to re-do the practical, what would you change?

k. Is there anything that you think can be done in order to improve the brewing practical/brewing apparatus?
l. Explain your answer (asked depending on the type of answer provided above)

Appendix 13

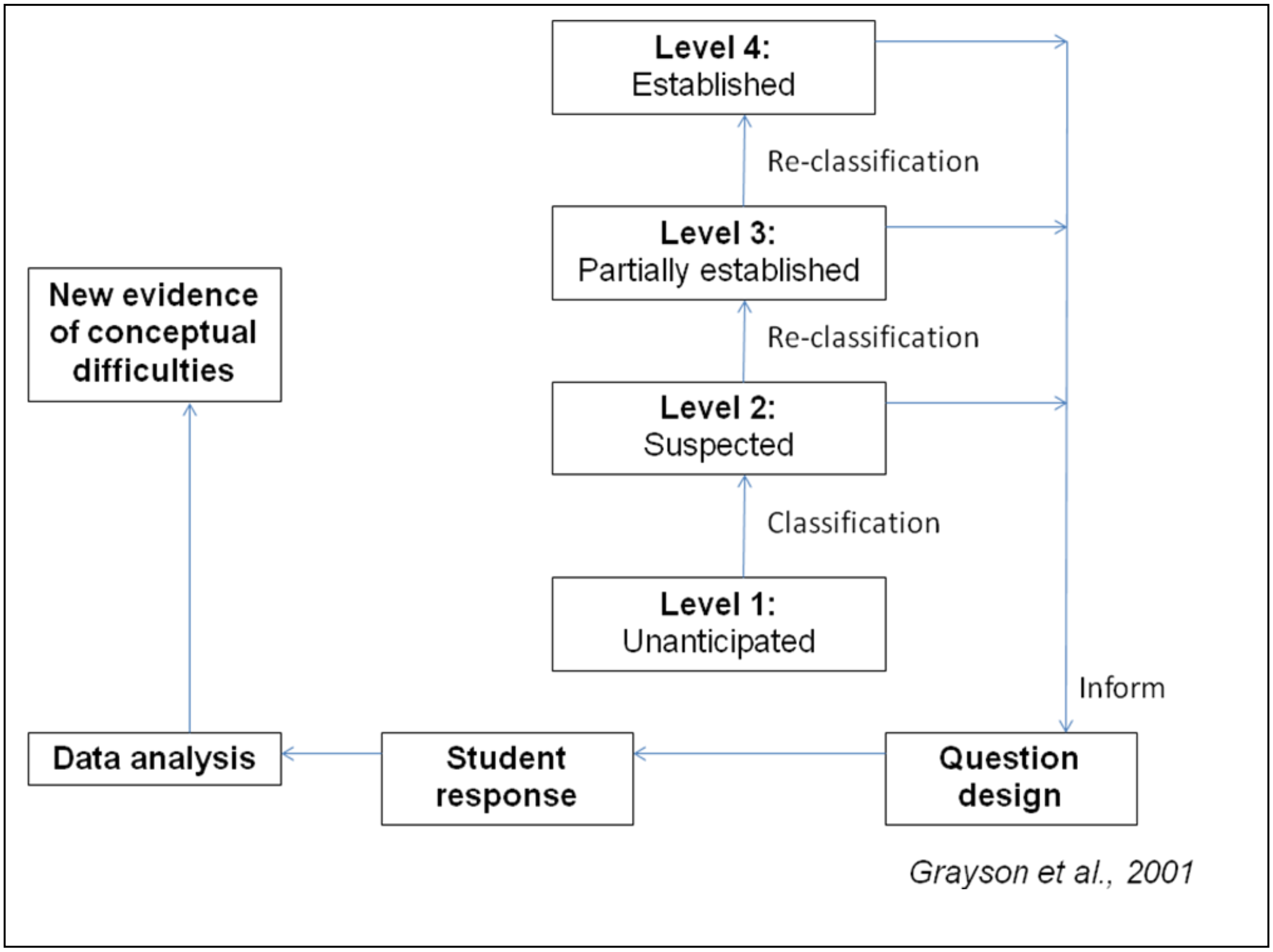


Figure 15: The four-level framework.