Chemistry Education Research and Practice

Dynamic Article Links ▶

Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

ARTICLE TYPE

Probing High School Students' Cognitive Structures and Key Areas of Learning Difficulties on Ethanoic Acid Using a Flow Map Method

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Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX
DOI: 10.1039/b000000x

The purpose of this study is primarily to explore high school students' cognitive structures and identify their learning difficulties of ethanoic acid through the flow map method. The subjects of this study were 30 grade 1 students from Dong Yuan Road Senior High Schoolin Xian in China. The interviews were conducted a week later after the instruction of ethanoic acid, and then interview narratives were transcribed into flow maps. The analysis on the flow maps showed that there existed a difference in the individual cognitive structure on etnanoic acid, higher academic achievers constructed more enriched cognitive structures and had higher scores for cognitive structural variables than lower academic achievers. Further, the results of the correlation analysis among the students' cognitive structure outcomes, academic achievement and the information processing modes revealed that there was a positive correlation between two of them to some extent; in general, the higher academic achievers tended to have higher cognitive structure outcomes and employ high-order information processing modes. The content analysis of the flow maps of all participants indicated that most students had known the main ideas of ethanoic acid, but the details were not complete, and the misconceptions were mainly relevant to the molecular constitution and structure of etnanoic acid as well as esterification reaction, while the knowledge of the physical properties and the acidity of ethanoic acid seemed to be mastered well relatively, as for the applications ofetnanoic acid, students only mentioned that it can be used as condiment.

Introduction

Many research studies have clearly demonstrated the importance of cognitive structures in subsequent learning as the building blocks of meaningful learning and retention of instructional materials (Snow and Lohman 1990).Cognitive structure is a hypothetical construct indicating the organization of concepts in learners' long-term memories and the relationships between them (Shavelson, 1974). Some researchers also use other terms, such as structural knowledge (Jonassen *et al.*, 1993)and knowledge structure (Champagne *et al.*, 1981; Nakiboglu, 2013) to describe cognitive structure. Ausubel (1963) highlighted the significance of this hypothetical construct as the principal factor in the accumulation of knowledge: "If existing cognitive structure is clear, stable, and suitably organized, it facilitated the learning and retention of new subject matter. If it is unstable, ambiguous, disorganized, or chaotically organized; it inhibits learning and retention"(p.217).

In the paradigm of constructivism, knowledge cannot be directly transmitted but must be actively constructed by individual leaner (Bodner, 1986; Fosnot, 1996). While, the pre-knowledge of specific domain in each learner's memory is always different, which is the dominant determination for reconstruction and information processing of the incoming stimuli (Taber, 2009; Nakiboglu, 2013).So, knowing what a learner knows is important for science instruction. The traditional paper-and-pencil tests are widely used to assess students' existing knowledge in chemical education, but instructors cannot get more information about what relationships between the concepts in their memory, as well as how they construct and organize the knowledge through them, so the exploration of learners' cognitive structures can be one of another important indicators in assessing what learners know (Tsai, 2001, 2005).Exploring the learners' cognitive structures can not only help educators know the knowledge structures, pre-knowledge and misconceptions in students' minds, but also help teachers know students' mental representations and information processing modes the students employ to acquire and organize knowledge. As a result of this, instructors can identify knowledge gaps, relate new materials to existing slots or anchors within the learners' cognitive structures and arrange teaching strategies in an appropriate way (Jonassen, 1987; Dirk Ifenthaler, 2009). The diagnosis of cognitive structures can act as a "topographic map" to identify key areas of learning difficulties and facilitate instructional interventions (Snow, 1989).

In recent decades, many researchers have tried to use various methodological techniques and analytical frameworks to conduct research on exploring students' thinking modes and cognitive structure (Taber, 2009), and the major issues in representing people's cognitive structures focused on how to represent cognitive structure in quantitative and through visual formats. For this purpose, numerous researchers have explored several methods for identifying people's cognitive structures, such as Word Association(Gunstone, 1980; Shavelson, 1972), Concept map (Joseph D. Novak , 1974) and Flow map (Anderson and Demetrius, 1993).Some researchers proposed that there are three major aspects in describing cognitive structures: the concepts or ideas acquired， the connections between concepts and the information processing strategies (Tsai and Huang, 2002). In order to indicate these three aspects of cognitive structures, five different variables of cognitive structure (Extent, Correctness, Integration, Availability and Analyses of information processing strategies) are included. Tsai and Huang (2005) introduced and compared the Free word association, Controlled word association, Tree Construction, Concept map and Flow map from the data collection, data analysis and the validity of the methods, the research result indicated that the flow map offer relatively more information in analyzing the variables about cognitive structures than the other methods and it is the only method that can describe the all variables of cognitive structure among these methods. On the other hand, flow map is created from the free expressions of the learners in a non-directive way, and it is a useful way to capture both the sequential and interrelated relationships of people's thought in probing learners' cognitive structures (Anderson and Demetrius, 1993). The use of the flow map method also accordance with current neuroscience models about human cognition and information processing (Anderson, 1997).

Since was first introduced by Anderson and Demetrius in 1993, flow map has been used in numerous studies (Bischoff, 1999, 2002, 2010; Tsai, 2000, 2001; Tsai and Huang, 2001; Dhindsa and Anderson, 2004; Özge ÖzyalçÕn Oskay, 2011, 2012;) as a tool to access and study knowledge structures among science learners, and many researchers asserted that the flow map was a particularly effective analytical tool for gaining insights into an individual's knowledge structures because it enabled the researchers to identify an individual's ideas or concepts, connections between the concepts and the information processing modes used in organizing the concepts. Therefore, within this study flow map was used to determine the students' cognitive structures.

In general, chemistry knowledge is abstract, strongly theoretical and logically structured. When facing with a lot of chemical symbols, complicated chemical reactions and theoretical chemical principles, students always have difficulties in chemistry learning (Yujuan Li, 2006; Ling Zhu and Houxiong Wang, 2011). In order to understand students' chemical learning difficulties better, lots of educators devoted themselves to study of identifying difficulties in chemistry learning (Shanshan Lu and Hualin Bi, 2013; Leilei Ma, 2014). However, the academic achievement scores provided by the traditional paper-and-pencil tests, according to which teachers can only know students who understand the knowledge well and who do not, but cannot detect the specific difficulties that students have to learn the knowledge. While, through probing students' cognitive structures about the specific subject, teachers can not only know acquired knowledge and misconceptions in students' minds, but also know the methods students employed to construct and organize the concepts, as a result, teachers can arrange their teaching strategies in a more appropriate way to promote students' learning outcomes (Tsai, 2001, 2005; Jonassen, 1987; Dirk Ifenthaler, 2009).Organic chemistry is an important content in the high school chemistry curriculum; it has highly integrated knowledge structure and closely logical content. However, some chemistry teachers found that there appeared some difficulties when students were first taught organic chemistry in their instruction, and the studies (Yuqun Huang, 2000; Ling Zhu and Houxiong Wang, 2011; Xialin Wang, 2014) about the students' learning difficulties of organic chemistry mainly reflected in the following three aspects: multitudinous organic substances were difficult to remember, the molecular structure of organic substances was too complicated and the organic reactions were difficult to understand. In addition, Students cannot accommodate suitable learning methods which are completely different from the way they used in former inorganic chemistry learning when representing organic matters with intricately chemical symbols, mastering multitudinous isomers and judging the unpredictable chemical products in organic reaction (Nathaniel P.Grove and Stacey Lowery Bretz, 2010; Yuqun Huang, 2000). Therefore, it is very necessary and significant to explore the students' learning characteristics and mode of thinking about the organic chemistry to help instructors to understand students' development of minds and arrange instruction strategies in an appropriate way (Xiaojie Wang, 2011; Xialin Wang, 2014). In this study, we chose ethanoic acid as focal concept to research the students' cognitive structure mainly for the following reasons. First, the ethanoic acid is the key content of compulsory chemistry course of high school in China, which is the typical organic compound for students learning the organic chemistry, a typical representative of oxygenated derivatives of hydrocarbon and the main ingredient of vinegar that students are very familiar with in daily life. In addition, the functional group of ethanoic acid is carboxyl, which is a very important functional group that is involved in abundant organic matters, and the reaction of carboxyl is one of core ideas in organic reactions (Jiane Bai, 2009; Jianjun Wang, Jiliang Yan and Xing Wu, 2012). Second, understanding the students' thinking modes and learning difficulties when they were first taught organic chemistry is very important for teachers to arrange their following teaching strategies (Yuqun Huang, 2000).And chemistry teachers found that students tended to have some misconceptions during the learning of ethanoic acid, such as the nature of esterification reaction and the experimental operations about the reaction between ethanoic acid and ethanol (Jiane Bai, 2009;). Therefore, exploring students' cognitive structure characteristics and learning difficulties about ethanoic acid can provide educators with information about the typical cognitive characteristics and information processing modes of organic chemistry, according to which teachers can design more appropriate teaching strategies for organic chemistry to optimize students' cognitive structures and enhance their meaningful learning.

Many researchers have ascertained the importance of exploring the learners' cognitive structures in science education, and tried to use several ways to represent learners' cognitive structures (Anderson and Demetrius, 1993; Tsai, 2001, 2002, 2005; Taber, 2009; Nakiboglu, 2013). The flow map method is an effective way to represent learners' cognitive structures both in quantitative terms and through visual formats (Anderson and Demetrius, 1993; Bischoff, 1999, 2002, 2010; Tsai, 2001, 2002, 2005;). While，We found that numerous studies have used the flow map method to explore the students' or teachers' cognitive structures within the specific domain knowledge, such as atomic model(Tsai, 2001), biological reproduction (Tsai and Huang, 2001), oxidation and reduction reaction (Bischoff, Avery, Golden and French. 2010), hybridization and bonds (Özge Özyalçõn Oskay, 2011) and so on, and the researchers could get more information about the subjects' cognitive structures through the method, which helped researchers understand individual characteristics of subjects' cognitive structures very well. But none of them studied the characteristics of subjects' cognitive structure about the organic chemistry, which was very important for chemistry education. On the other hand, there are some studies about the organic chemistry teaching and learning in China, and the study focus mainly on learning difficulties and the corresponding teaching strategies (Yuqun Huang, 2000; Xialin Wang, 2014), teaching design (Jianjun Wang, Jiliang Yan and Xing Wu, 2012), students' cognitive structure within the organic chemistry learning (Xiaojie Wang, 2011) and so on. But the method was used to explore students' cognitive structures and learning difficulties in these studies was mainly the traditional paper-and-pencil test, and the methods, such as word association and the flow map, were rarely used because of a relatively late start of study about cognitive structure. Therefore, in this study we wanted to employ the flow map method to probe students' cognitive structures on ethanoic acid, in order to study the characteristics of Chinese students' cognitive structures about the organic chemistry. Our research questions mainly contained the following three aspects: first, what pattern students' cognitive structures are constructed after instruction and are there any differences among the students' individual cognitive structures about ethanoic acid? Second, what information processing modes students tended to use during learning of ethanoic acid? Third, what are the students' learning difficulties about ethanoic acid?

Methodology

This study was carried out in Dong Yuan Road Senior High School in Xi'an. Before the interviews were conducted, the researchers informed the students that the aim of our study was to understand what they had learned about ethanoic acid and try to find if there were any ambiguous concepts in learning ethanoic acid. We introduced to the students we would ask them three questions and they just answer as much as they like. And we also told them in this research by probing their knowledge structures about ethanoic acid could help teachers design the appropriate teaching strategies targeted to promote effective teaching and meaningful learning, and the data offered by them may be published in the future but is anonymous. And we promised the outcomes of their interviews and the scores obtained from the paper-and-pencil test would not be told to anybody else but themselves. All participants of our study were volunteered and would like to talk to our postgraduates who conducted the interviews. In addition, the flow map method requires the participants are not disturbed by the researchers during the interviews, so the interview questions were presented in a non-directive way. And the researchers told participants that they could tell the researchers what they know about ethanoic acid and express their ideas freely, the answers to the questions were respected and would not to be judged to be right or wrong. The interviews were carried out in a friendly atmosphere. At the same, the study was approved by both Dong Yuan Road Senior High School and Shaanxi Normal University, and with the informed consent of the participants.

Subjects

The subjects of the study consisted of 30 Senior Grade 1 students (15 years old) from a class of Dong Yuan Road Senior High School in Xi'an, the capital city of Shaanxi province in China. After a week of instruction about ethanoic acid, 30 students (16 boys and 14girls) were selected considering different academic achievement levels and the skills of expressing their ideas for further interviews. Among of them, 10 students had high academic achievements, 10 students had medium academic achievements and the other 10 had relatively low academic achievements.

Data collection

First of all, it should be noted that both interviews and paper-and-pencil tests in this study were carried out in Chinese, which is the language of instruction used in the school. The interview questions and the test paper reported in the paper were translated into English by two researchers together, refined by a postgraduate whose major was English and added in the appendix. The original Chinese version of the test is available from author.

The interviews were conducted a week later after the instruction of ethanoic acid, then the interview narratives were transcribed into flow maps according to the process of creating flow map developed by Anderson and Demetrius (1993) for further analyses.

In addition, students' test scores on a paper-and-pencil test about the ethanoic acid were also collected for correlation analyses later. The reliability of the test has been analyzed using the SPSS 21.0 (Statistical Product and Service Solutions); the value of Cronbach's Alpha is 0.89, which indicated that the test is of good internal consistency coefficient. For validity of the test, a university professor in chemistry education, two Doctors in chemistry education and a high school chemistry teacher who has more than 10 years teaching experience analyzed the test in detail together, they were agreed that the test covering the comprehensive knowledge of ethanoic acid and the level of difficulty is moderate for students who were first taught ethanoic acid, and the test has a good content validity. Therefore, the scores derived from the paper-and-pencil test were reliable in the study.

Flow map method

In the study, flow maps were used to determine the individual cognitive structure of 30 students about the subject of ethanoic acid. In order to elicit learners' cognitive structures about ethanoic acid, non-directive questions were asked by researchers as follows:

1. Could you tell me the main ideas of ethanoic acid?
2. Could you tell me more about the ideas you have mentioned?
3. Could you tell me the relationships among the ideas you have already told me?

In order to obtain students' descriptions about ethanoic acid as complete as possible, after a student's answers about these questions were tape-recorded, each learner was asked to listen to his/her ideas immediately, so that he/she could recall additional information that had not been mentioned previously. This period is called a "meta-listening" technique (Tsai, 1998, 2000, 2001). After all of the interviews above were tape-recorded, each student's interview narrative was transformed to the format of "flow map" according to the process of creating flow map developed by Anderson and Demetrius (1993). When diagramming the flow maps, the following rules were used. First, each completed thought uttered by the respondent was entered as a statement in the flow map and linked by an arrow to the next uttered statement; second, compound sentences were separated into component clauses, and each clause entered in sequence as a separate statement; third, after all statements had been entered in sequence, statements containing recurrent thought or cross-references were identified and recurrent arrows drawn linking the related statements, when recurrent thought occurred , the arrows were linked to the earliest statement where the thought had been expressed in the sequence (Anderson and Demetrius, 1993).

There are two types of arrows in the flow map. The liner or serial arrows show the sequential flow of the learners' ideas, and the recurrent arrows indicate the relationships among the statements displayed in the flow map. Taking the student A's flow map for example, as shown in figure 1, the recall record of student A begins with the condensed structural formula of ethanoic acid, then the acidity of ethanoic acid, the esterification reaction , the common name of ethanoic acid and so on. For recurrent arrows, the statement 2, "Ethanoic acid is a weak acid in aqueous solution, and has the common properties of acid" stated ethanoic acid had the common properties of acid, while, statement 4, 5, 6, 7, 8 described the specific performances of acidity, so there was a recurrent arrow drawn back to statement 2 from statement 4, 5, 5, 7, 8 respectively. The numbers of liner and recurrent connections in the flow maps were calculated for the students' flow map scores. These scores were regarded as the indicator of conceptual achievement.

Figure 1 and Figure 2 are samples of students' flow maps derived from the interview narratives of students A, student B and student C. Among of them, student A was the one who had a high academic achievement, while student B and student C were medium and low respectively.

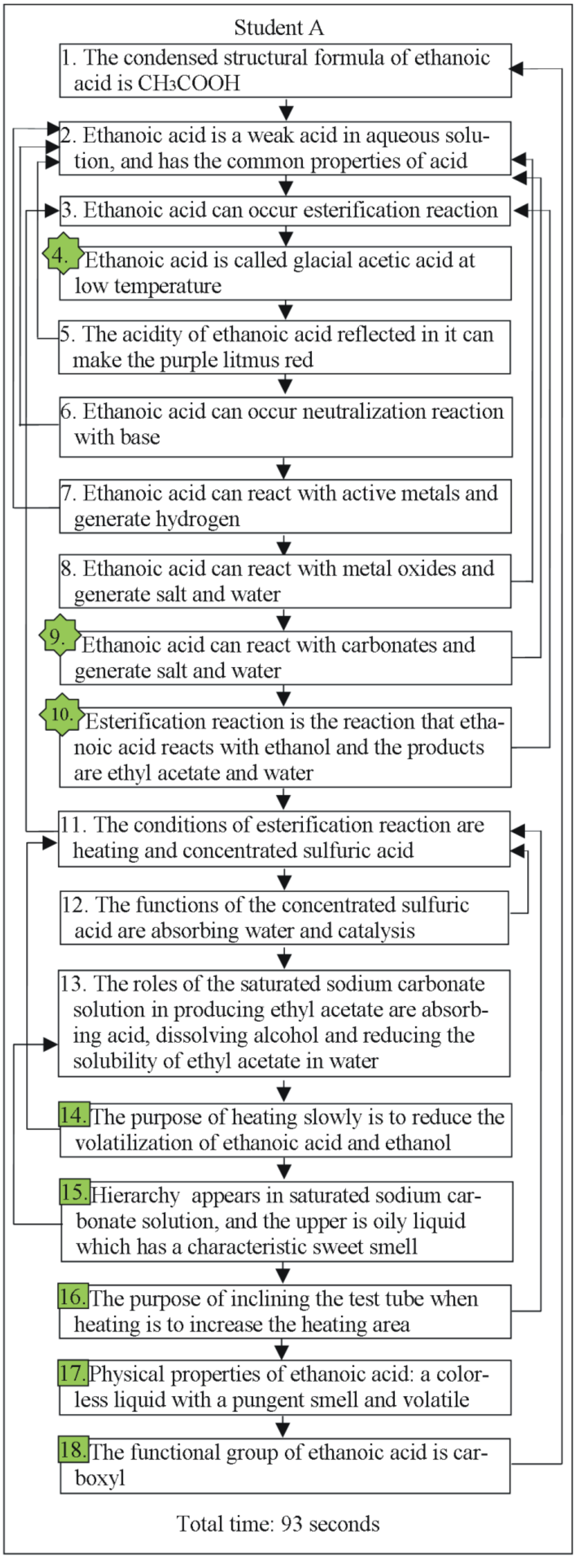


Fig.1 A sample of students' flow maps based on student A's narrative on the ethanoic acid

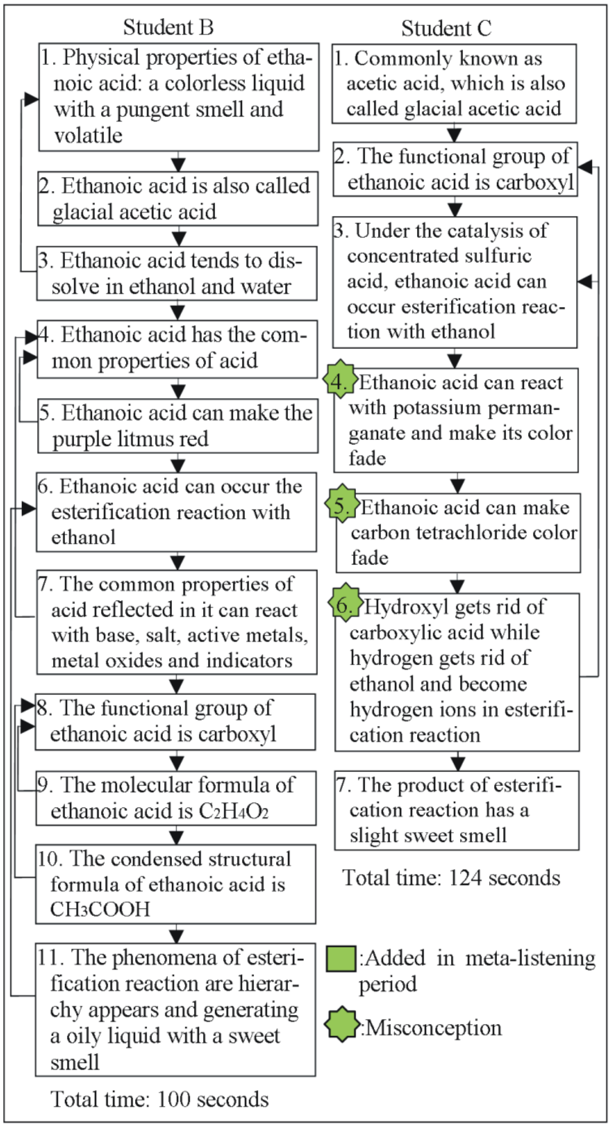


Fig.2 Two samples of students' flow maps based on students' (student B and student C) narratives on the ethanoic acid

As a result, the following five different variables could be provided by the flow map to represent the students' cognitive structure outcomes in quantitative terms:

1. *Extent:* the total number of ideas shown in the flow map.
2. *Richness:* the total number of recurrent linkages which represent the connection between the two ideas.
3. *Flexibility:* flexibility indicates students' idea change as a result of the meta-listening period, equaling to the total number of ideas minus the number of ideas elicited before the meta-listening period.
4. *Integration:* the connection of cognitive structures. Using the proportion of recurrent linkages to represent, equaling to the number of recurrent linkages/(number of ideas + number of recurrent linkages).
5. *Misconceptions:* number of misconceptions shown in the flow map; a smaller number of misconceptions indicating greater correctness.
6. *Information retrieval rate:* information retrieval rate is represented by statement per second. As described previously, the time measured is only applied to the first part of the interview; this variable is defined as number of ideas elicited /total time used in that interview period.

Through a series of content analyses of the students' flow maps, the students' information processing modes could be also captured. In order to understand the students' usage among these different modes of processing knowledge about ethanoic acid deeply, the way of each of the students' statements presented in the flow maps was categorized into one of these five levels (from low to high): defining, describing, comparing and contrasting, conditional inferring, and explaining, according to a system developed by Smith and Meux (1970). With reference, take the ethanoic acid for example, these categories defined were as follows (Tsai 1999):

1. *Defining:* providing a definition of a concept or a scientific term, and the basic properties of a substance. E.g., the esterification reaction is the reaction that carboxylic acid reacts with alcohol and generating ester and water.
2. *Describing:* depicting a phenomenon, a process or a fact. In this study, the dates belong to describing contain experimental phenomena, material properties and scientific terms. E.g., the chemical formula of ethanoic acid is $C_2H_4O_2$, ethanoic acid can make the purple litmus (acid-base indicator) red.
3. *Comparing and contrasting:* describing the relationships between (or among) subjects, things, or methods. E.g., the acidity of ethanoic acid is weaker than sulfuric acid, hydrochloric acid and nitric acid, but is stronger than carbonic acid.
4. *Conditional inferring:* a description about what will happen under certain conditions. E.g., ethanoic acid has the common properties of acid, so it can occur neutralization reaction with base.
5. *Explaining:* presenting an account to justify the causality of two facts or events. E.g., ethanoic acid can be used to produce carbonic acid because its acidity is stronger than carbonic acid.

The reliability of flow map method is determined by a second independent researcher who is an expert in chemistry education to diagram the students' interview narratives according to Anderson and Demetrius' procedure (Anderson & Demetrius, 1993). In this study, the inter-coder agreement for liner linkages was 0.90, and for recurrent linkages was 0.86. In general, it is considered sufficient for narrative analysis if the reliability is greater than 0.80 (Tsai & Huang, 2001; Wu & Tsai, 2005). Therefore, this method was deemed to be sufficiently reliable for the purposes of this study. Similarly, the inter-coder agreement for content analysis of information processing modes was 0.89, which indicated that the two researchers had the same way of categorization on 89% of students' ideas of information processing modes. Therefore, the content analysis of information processing modes in this study was viewed as sufficiently reliable.

Results

Student's Cognitive Structures Outcomes of Ethanoic Acid

Table1 The cognitive structure outcomes of Student A, B and C

Variables	Student A	Student B	Student C
Extent	18	11	7
Richness	12	6	2
Integration	12/(18+12)=0.40	6/(11+6)=0.35	2/(7+2)=0.22
Misconceptions	3	0	3
Flexibility	5	0	0
Information retrieval rate	18/93=0.19	11/100=0.11	7/124=0.06

Table1 shows the quantitative outcomes of the three flow maps in Figure1 and Figure 2. Clearly, among them student A seems to construct the best cognitive structure of ethanoic acid and have the best cognitive structure outcomes in light of these cognitive structural variables. Although student B is not as good as student A in terms of extent, richness and flexibility and integration, there did not appear misconceptions in his narrative. Relatively, student C has the lowest information retrieval rate, he only recalled 7 ideas during 124 seconds, and 3 of them are misconceptions .We found that student C could not describe his ideas continuously and he needed a long time to recall each idea during the interview. The analysis indicates that higher academic achievers tend to construct more enrich cognitive structure and have higher scores for these variables.

Table2 Relationships between science achievement and cognitive structure variables (N=30)

	EXT	RICH	INTG	MISCON	FLEX	IRR	ACHV
EXT		796**	.462*	-.074	.106	.189	.359
RICH			.809**	-.039	.401*	.154	.516**
INTE				-.095	.234	.250	.347
MISCON					.22	-.409*	-.091
FLEX						-.098	.381*
IRR							.175
ACHV							

**p<.01*p<.05

Key: EXT: extent; R1CH: richness; INTG: integration; MISCON: misconceptions; IRR: information retrieval rate, and FLEX: flexibility; ACHV: achievement score from paper-and-pencil test

Table 2 Shows correlation analyses between students' academic achievement scores gathered from a paper-and-pencil test and the cognitive structure variables. The result indicates that students' achievement score is closely related to richness and flexibility ($p<.01$, $p<.05$). Higher achievers (according to the paper-and-pencil test) tend to have greater richness and stronger flexibility than lower achievers. The correlated matrix also suggests that the extent of students' cognitive structures is related to their richness and integration ($p<.01$, $p<.05$), and the richness of the cognitive structures is related to their integration and their flexibility ($p<.01$, $p<.05$). Even more, the misconception of students' cognitive structures is negative related to their information retrieval rate, the number of the misconceptions is more, the information retrieval rate tends to lower.

Content Analyses of Students' Information Processing Strategies

This study also conducted correlation analyses between students' cognitive structure outcomes and information processing modes as well as correlation analyses between students' academic achievement scores and information processing modes. The results are shown in Table 3.

Table 3 The correlation analyses about students' information processing strategies (N=30)

	DFN	DSCB	CMPR	CNDTN	EXPLN
EXT	.173	.663**	.283	.470**	.739**
RICH	.219	.579**	.235	.557**	.749**
INTG	.106	.276	.208	.361	.567**
MISCON	.232	.036	-.174	-.026	.069
IRR	-.173	.036	.111	-.101	.259
FLEX	.093	.284	-.12	.183	.277
ACHV	-.025	.169	.243	.384*	.532**

**p<.01*p<.05

Key: DFN: defining; DSCB: describing; CMPR: comparing; CNDTN: conditional inferring, and EXPLN: explaining; ACHV: achievement score from paper-and-pencil test

Table 3 shows the results of content analyses of students' information processing strategies. The result of correlation analysis between students' cognitive structure outcomes and information processing strategies reveals that the cognitive structural variables "extent", "richness" and "integration" are positively related to the highest information processing strategy, that is, explaining($p<.01$), which is the one correlated with most of the cognitive structure variables. In addition, the "extent" and "richness" of cognitive structure are also positively related to "describing" and "conditional inferring" information processing modes ($p<.01$).

The result of correlation analysis between students' academic achievement scores and information processing modes indicates that students' academic achievement scores are positively related to the "conditional inferring" and "explaining" information processing modes ($p<.05$, $p<.01$). This result suggests that higher academic achievers tend to express their ideas in relatively higher-order information processing modes (e.g., conditional inferring and explaining), which concurs with Tsai's (2001) conclusions about the atomic model.

The Misconceptions and Learning Difficulties about Ethanoic Acid

The study also analyzed the concepts students recalled about ethanoic acid through examining all of the flow maps derived from the 30 participants' interview narratives. All of the ideas on ethanoic acid displayed on the flow maps derived from students' interview narratives are summarized in Table 4.The primary knowledge of ethanoic acid contains the molecular constitution and structure of ethanoic acid, physical properties of ethanoic acid, chemical properties of ethanoic acid and its applications, and chemical properties of ethanoic acid can be divided into the acidity of it and the esterification reaction (Xinqi Song, Jing Wang and Wending Li., 2011; The Ministry of Education of China, 2006). Through analyzing the concepts recalled in the interviews, both the correct and incorrect concepts recalled, educators can not only get the information about what students learned about ethanoic acid within the five aspects mentioned above, but also identify students' misunderstandings about the ethanoic acid during the learning. As a result, teachers may generally know whether the students have acquired the major ideas of the instruction and the students' learning difficulties within the subject, so that they can arrange the teaching strategies effectively to enhance their instruction and students' learning outcomes.

Table 4 Major concepts students recalled about the ethanoic acid in the flow-map interviews

		Major concepts students recalled	%
MCS	CORCON	The functional group of ethanoic acid is carboxyl	76.67
		The condensed structural formula of ethanoic acid is CH_3COOH	63.33
		The molecular formula of ethanoic acid is $C_2H_4O_2$	56.67
		The properties of ethanoic acid are determined by its functional group, namely carboxyl	20.00
		Ethanoic acid is an important derivative of hydrocarbon	3.33
	MISCON	The chemical formula or molecular formula is CH_3COOH	16.67
		The functional group of ethanoic acid is –COOH, which contains hydroxyl and hydrogen ion	16.67
		The structural formula of ethanoic acid is $C_2H_4O_2$	3.33
PHY	CORCON	Ethanoic acid is a colorless liquid with a pungent smell	83.33
		Commonly known as acetic acid and glacial acetic acid	53.33
		Ethanoic acid tends to dissolve in ethanol and water	36.67
		Glacial ethanoic acid is pure substance	26.67
	MISCON	Ethanoic acid is called glacial acetic acid at low temperature	33.33
ACDT	CORCON	Ethanoic acid can make the purple litmus red	70.00
		Ethanoic acid has the common properties of acid	50.00
		Ethanoic acid reacts with active metals and produce hydrogen	50.00
		Ethanoic acid reacts with base (sodium hydroxide) which is called neutralization reaction	46.67
		Ethanoic acid reacts with metal oxides and generate salt and water	43.33
		Ethanoic acid reacts with carbonates and generate salt and water	43.33
		The acidity of ethanoic acid is weaker than sulfuric acid, hydrochloric acid and nitric acid, but is stronger than carbonic acid	16.67
		The acidity of ethanoic acid is relatively strong and it can be used to produce carbonic acid	6.67
ESTR	CORCON	Ethanoic acid can occur esterification reaction with ethyl alcohol and generates ethyl acetate and water	96.67
		The conditions of eaterification reaction are heating and concentrated sulfuric acid as catalysis	43.33
		The roles of saturated sodium carbonate solution in producing ethyl acetate are absorbing acid, dissolving alcohol and reducing the solubility of ethyl acetate in water	40.00
		There is a colorless oily liquid with a sweet smell above the saturated sodium carbonate solution	40.00
		The nature of the esterification reaction is the hydroxyl group getting rid of carboxylic acid while the hydrogen getting rid of alcohol	36.67
		The functions of the concentrated sulfuric acid are absorbing water and catalysis	30.00
		In order to prevent suck-back, the glass tube cannot insert below the liquid level in the experiment	20.00
		The esterification reaction belongs to substitution reaction as well as reversible reaction	20.00
		The purpose of heating slowly is to reduce the volatilization of ethanoic acid and ethanol	16.67
		The purpose of inclining the test tube when heating is to increase the heating area	16.67
		The order of adding experiment reagents is ethyl alcohol, Concentrated Sulfuric acid and ethanoic acid	13.33
	MISCON	The eaterification reaction is the reaction that ethanoic acid reacts with ethanol and the products are ethyl acetate and water	13.33
		The hydroxyl group gets rid of alcohol while the hydrogen gets rid of carboxylic acid in the esterification reaction	6.67
		Concentrated sulfuric acid is used to collect ethyl acetate	3.33
		Ethanoic acid can occur the addition reaction	3.33
		Ethanoic acid can make potassium permanganate and carbon tetrachloride color fade	3.33
APP	CORCON	Commonly known as ethanoic acid, which is the major ingredient of vinegar	53.33
		Ethanoic acid can be used as condiment	6.67

Key: %: The percentage of students recalled the concept in the flow-map interviews, the total number of students participated in the interviews is 30(N=30); MCS: molecular constitution and structure of ethanoic acid; PHY: physical properties of ethanoic acid; ACDT: acidity of ethanoic acid; ESTR: esterification reaction; APP: applications; CORCON: correct conceptions; MISCON: misconceptions

The molecular constitution and structure of ethanoic acid: In organic chemistry, the knowledge of the molecular constitution and structure mainly contains molecular/chemical formula, structural formula, condensed structural formula and functional group. The teaching aim for the molecular constitution and structure is that students can distinguish these chemical symbols and use different symbols representing organic matters correctly. Tables 4 shows that most students acquired the functional group, condensed structural formula and molecular formula of ethanoic acid well, 76.67% of the students stated the functional group of ethanoic acid was carboxyl, 63.33% and 56.67% of the students correctly described the condensed structural formula and molecular formula of ethanoic acid respectively. However, influenced by the thinking model of inorganic chemistry learning, a few of students were confused about molecular formula, chemical formula and condensed structural formula, 16.67% of the participants stated that the molecular or chemical formula of ethanoic acid was CH_3COOH, 3.33% of the participants stated its structural formula was $C_2H_4O_2$. While some students could not understand the structural feature of carboxyl, 16.67% of the participants stated that carboxyl contained hydroxyl and hydrogen ion.

Physical properties of ethanoic acid: Physical properties mainly contain color, state, smell, volatility, solubility and common name of matter. Table 4 indicates that students mastered the physical properties of ethanoic acid well, especially its pungent smell, 83.33% of the participants mentioned it correctly. This probably because ethanoic acid is closely related to students' daily life, they often contact it, and they are familiar with its smell. And in terms of its common name, 53.33% of them stated that it was commonly known as acetic acid and glacial acetic acid, but because without the correct understanding for the origin of glacial acetic acid, 33.33% of them had a misconception that ethanoic acid is called glacial acetic acid at low temperature.

Acidity of ethanoic acid: On the basis of the common properties of inorganic acid learned previously, most students could state the acidity of ethanoic acid specifically without misconceptions. 70.00% of the students mentioned that ethanoic acid could make the purple litmus red, because it could be verified by observing experimental phenomenon of obvious color changing; hence the students remembered it clearly. Nearly half of the participants recalled that ethanoic acid could react with active metals and produce hydrogen, ethanoic acid could have neutralization reaction with base, and ethanoic acid could react with carbonates and metal oxides. While with regard to the comparison of the acidity between ethanoic acid and some inorganic acids, the understanding level is relatively low, 16.67% of the participants stated the acidity of ethanoic acid was weaker than sulfuric acid, hydrochloric acid and nitric acid, but was stronger than carbonic acid; and only 6.67% of them mentioned that it could be used to generate carbonic acid because its acidity was relatively strong.

The esterification reaction: The esterification reaction is the focal point in the learning of ethanoic acid (Jiane Bai, 2009; The Ministry of Education of China, 2006), teachers often emphasize it in the classroom. As a result, most of students mentioned the general knowledge of esterification reaction. 96.67% of them stated that ethanoic acid could have esterification reaction with ethyl alcohol and generate ethyl acetate and water. However, the knowledge in detail seems not to be mastered very well, only about 40% of them stated the conditions, nature and phenomenon of esterification reaction, and much less students recalled the functions of the concentrated sulfuric acid and announcements in the experiment. There appeared some misconceptions as well, 13.33% of participants could not transfer the knowledge effectively and have misunderstanding for the concept of esterification reaction, they stated that the esterification reaction was only the reaction that ethanoic acid reacted with ethanol and the products were ethyl acetate and water. 6.67% of the participants stated that the nature of the esterification reaction was the hydroxyl group getting rid of alcohol and hydrogen getting rid of carboxylic acid.

Applications of ethanoic acid: The students' overall cognitive level about the applications of ethanoic acid is low. 53.33% of the students stated that it was the major ingredient of vinegar, and 6.67% of them only stated it could be used as condiment. Actually, ethanoic acid is an important industrial material and chemical reagent; its applications are not limited to be used as condiment. Teachers should introduce the applications of ethanoic acid from the more widely perspectives to expand students' knowledge.

Conclusions and Implications

Science educators encourage the use of multiple ways to assess learners' learning outcomes in order to gain a better understanding about students' concepts in science (Wu & Tsai, 2005). Probing students' cognitive structures using the flow map method, educators can get students' natural stream of thoughts and interconnection of concepts with minimal intervention. In addition, through analyzing students' flow maps, educators can also analyze students' cognitive structures in quantitative terms using the cognitive structure variables as described previously.

The findings of analysis about students' cognitive structures of ethanoic acid show that the individuals constructed different cognitive structures even in the same learning environment. As a result, their scores of cognitive structural variables are different, higher academic achievers tended to have higher scores for the extent, richness, integration, information retrieval rate and flexibility as well as lower scores for misconceptions than lower academic achievers. In addition, the correlation analysis revealed that students' academic scores are positively related to richness and flexibility of cognitive structures of ethanoic acid, which is different from Tsai's (2001) conclusion about atomic model that the academic scores are positively related to extent, richness, information retrieval rate and integration. The difference may due to the different subjects have different learning models and different students may have different cognitive characteristics. Moreover, different cultural context and teachers' different instruction styles may also be factors that affect students' cognitive characteristics.

The results of the analysis about students' information processing modes in this study indicate that students who have larger extent, richer and more integrated texture of cognitive structures tended to express their ideas in relatively high information processing modes (e.g., conditional inferring and explaining). At the same time, higher academic achievers also tended to employ conditional inferring and explaining to organize their knowledge. According to the results, we can infer that the use of high-level information processing modes (e.g., conditional inferring and explaining) requires well developed cognitive structures and high academic scores, which concurs with Tsai's (1999, 2001, 2005) conclusions. In addition, we propose that the richer connections between concepts and the use of high-order information processing strategies may mutually reinforce one another, so chemistry teachers are encouraged to use effective teaching strategies to help students employ higher-order information processing operations, the use of POE (Prediction-Observation-Explanation) instructional activities (White & Gunstone, 1992; Liew and Treagust, 1995; Palmer, 1995; Tsai, 2005) and cooperative learning strategies (Soyibo & Evans, 2002; Marinopoulos & Stavridou, 2002) are advised.

In this study, students' major ideas and learning difficulties are identified by content analysis of 30 students' flow maps. It seems that students' cognitive structures about ethanoic acid put more emphasis on the molecular constitution and structure of ethanoic acid, acidity of ethanoic acid and eaterification reaction. Especially, the esterification reaction is teaching important point as well as teaching difficult point in teaching of ethanoic acid (Jiane Bai, 2009;Jianjun Wang, Jiliang Yan and Xing wu, 2012;), teachers always emphasis it in the classroom, so the ideas about esterification reaction appeared most in the students' flow maps. While the concepts about physical properties and applications of ethanoic acid received relatively less attention among these students.

Furthermore, the result also suggests that the learning difficulties of ethanoic acid mainly reflected in its molecular constitution and structure and esterification reaction. As for the molecular constitution and structure of ethanoic acid, students' misconceptions mainly reflect in two aspects. First, students were confused about the concepts and meanings of chemical/molecular formula, condensed structural formula and structural formula; second, students did not understand the structural feature of carboxyl correctly. All of these because the fact that there are more chemical symbols used to represent organic matters (Yuqun Huang, 2000;Xialin Wang, 2014), mainly contain molecular formula, condensed structural formula and structural formula, which is completely different from it in inorganic chemistry learning, the molecular formula is the only chemical symbol used to represent matters. On the other hand, there are too many functional groups in organic chemistry, making students confused and generate misconceptions. While, the structural features of the matters are the foundation of the further learning, high school chemistry teachers should emphasize the characteristics of these chemical symbols to help students remember and distinguish them correctly(Yaowu Guan, 2005; Min Xu, 2012). Otherwise, teachers should also pay attention to concept teaching because there are so many concepts in the learning of organic chemistry that students have difficulties to remember and understand.

Moreover, students' learning difficulties of eaterification reaction mainly reflected in the understanding of the concept and nature of esterification reaction, which mainly resulted from the students' poor knowledge transfer ability and poor understanding of the nature of organic reaction (Yuqun Huang, 2000; Xiaojie Wang, 2011). The esterification reaction is first taught during the learning of ethanoic acid in China, and the reaction of ethanol and ethanoic acid is taken for the example in the instruction. As a result, most students cannot transfer the knowledge effectively and tend to acquire the knowledge that esterification reaction is the only reaction that ethanol reacts with ethanoic acid and generates ethyl acetate and water. In addition, most high chemistry teachers tend to tell students the conclusion about the reaction directly, instead of teaching it from the perspective of functional group and chemical bond breaking, so most students just remember simply, but not to understand it. As we known, the nature of organic reaction is the reaction of functional groups; teachers are not encouraged to instruct using the specific matters, but expand to functional groups (Qiang Chen, 2009; Min Xu, 2012). So high school chemistry teachers are encouraged to pay more attention to the cultivation of students' transfer ability in the classroom and employ the reaction mechanism in the instruction, which will promote students to understand better and enhance students' meaningful learning (Qiang Chen, 2009).

In summary, the flow map method is a useful method that can be used to describe three major aspects of cognitive structures: the concepts or ideas acquired, the connections between concepts and the information processing strategies in quantitative and through visual formats (Tsai, 2001; Tsai and Huang, 2001, 2002; Dhindsa and Anderson, 2004; Bischoff *et al.*, 2010). The analysis of students' flow maps can provide a rich variety of dimensions for teachers and professional evaluators to assess students' cognitive structures, and quantitative scores of cognitive structure variables (extent, richness, integration, misconceptions, information retrieval rate and flexibility) can be used as a part of students assessment in addition to scores gathered from traditional paper-and-pencil tests. Otherwise, the information obtained through analyzing students' flow maps can be also used to identify students' cognitive development, misconceptions, strengthens and weakness of each student's knowledge within a specific scientific topic, which can not only help teachers find the defects in their teaching, provide more information for teachers to optimize their teaching design, but also help students engage in metacognitive learning and thus enhance students' learning outcomes. The findings derived from this study suggest that chemistry teachers could try to use the flow map method to probe students' cognitive structures and identify the learning difficulties of specific topics in addition to paper-and-pencil tests. In addition, in order to understand students' knowledge acquired better, researchers and teachers are encouraged to employ multiple methods to assess and evaluate students in science education together.

The Limitations of the study and the Further study

Although the flow map method is an effective method that can be used to obtain more and detailed information of the cognitive structure with minimum interference, there are some limitations in this study. Firstly, students' speed of utterance, some students were skilled in expressing and some students might be nervous in the interview, all of these would influence the outcomes of students' cognitive structure.

Secondly, in this study, we elicited the students' cognitive structures about ethanoic acid through the interviews. While, there is some implicit knowledge in students' memories, which is significant for learning and teaching but cannot be elicited directly (Taber, 2014). So the flow maps derived from students' narrative in the study may only be a part of students' cognitive structure but not the whole. On the other hand, the students' cognitive structures about the specific domain develop along with the learning, so the results of our study are only snapshots of students' cognitive structures (Taber, 2013). Therefore, as students' cognitive structures are so complex, multidimensional, as well as somewhat in flux (Mortimer, 1995; Petri & Nidderer, 1998; Taber, 2000, 2001, 2013, 2014), we cannot represent them with a simple fixed and monolithic underlying structure.

Thirdly, a lot of important knowledge about ethanoic acid is not suitable to describe in orally, such as structural formula and chemical equation of organic reaction, both of which were not mentioned in the narratives of students. Therefore, if combining the expression verbally and writing together, more and detailed information of the students' cognitive structure will be obtained, then the flow maps representing more complete cognitive structure will be created. This is the research direction in the further study.

In addition, the sample of this study is only 30 students' from the same class of a school, so the conclusions of this study may be not much representative.

However, this study is only the preliminary study. In this study, we explored 30 students' cognitive structures and identified the learning difficulties of ethanoic acid, so that we can disclose the defects of instruction and provide some teaching strategies for instruction of ethanoic acid. In terms of the learning difficulties of ethanoic acid concluded from this study, that is, the molecular constitution and structure of ethanoic acid and esetrification reaction, we will optimize the teaching design through emphasizing the conceptual change and reaction mechanism, and apply the optimized teaching design in teaching practice; and then exploring the students' cognitive structures using the flow map method to study the effects of the teaching strategies.

In addition, in our further study, we are planning to select more students from different classes and different schools, and choose more subjects, such as ethyl alcohol and acetaldehyde and so on to explore students' cognitive structures using the flow map method. So that we can understand the students' cognitive characteristics and learning model of organic chemistry better, as a result, teachers will be provided effective teaching strategies for organic chemistry.

Acknowledgement

We would like to acknowledge the support of Chinese National 985InnovationPlatform for Development Outstanding Universities of China. We are gratefully acknowledge the support and collaboration of the teachers and students in Class 3 and Grade 1 of Dong Yuan Road Senior High School in Xi'an, the capital city of Shaanxi province in China who participated in the study.

Appendix

1. Ethanoic acid is the major ingredient of vinegar, which of the following statements about acetic acid is correct ( )
   a. Ethanoic acid is a liquid with a pungent smell
   b. There are four hydrogen atoms contained in the ethanoic, so ethanoic acid is not monoacid
   c. Ethanoic acid can have the esterification reaction at normal temperature
   d. Ethanoic acid can't make the purple litmus red because its acidity is relatively weak
2. Which of the following substances is carboxylic acid ( )
   a. CH_3CH_2OH b. CH_3CHO
   c. CH_3COOH d. $CH_3COOCH_2CH_3$
3. The esterification reaction is an important reaction type of organic reactions, which of the following statements about the esterification reaction is correct ( )
   a. The concentrated sulfuric acid is an essential reactant of the esterification reaction
   b. The esterification reaction can be regarded as a substitution reaction
   c. Ethanol is the necessary reactant in the esterification reaction
   d. The reactants will completely convert into products in the esterification reaction
4. Vinegar is a common condiment, and there are 3%-5% ethanoic acid contained in it. Which of following statements about acetic acid is correct ( )
   a. Ethanoic acid tends to dissolve in ethanol and water
   b. Vinegar can be used to dissolve the limescale in a kettle
   c. Glacial acetic acid is the solid of acetic acid, and it is a mixture
   d. Ethanoic acid is ionic compound, because it will ionize and produce hydrogen ions when dissolved in water
5. Which of the following chemical symbols is correct ( )
   a. The structural formula of ethylene is $CH_2=CH_2$
   b. The empirical formula of acetic acid is CH_2O
   c. The condensed structural formula of ethanol is C_2H_6O
   d. The condensed structural formula of ethanoic acid is $HCOOCH_3$
6. Which of the following mixture can be separated using separating funnel ( )
   a. Ethanol and acetic acid b. Ethanol and water
   c. Acetic acid and water d. Benzene and water
7. Which the statements about the esterification reaction between acetic acid and ethanolis correct ( )
   a. The hydroxyls of acetic acid combine the hydrogen atoms of ethanol into water
   b. The hydroxyls of acetic acid combine the hydrogen atoms of the hydroxyls of ethanol into water
   c. The hydrogen atoms of the hydroxyls of acetic acid combine the hydroxyls of ethanol into water
   d. The hydrogen atoms of acetic acid combine the hydroxyls of ethanol into water
8. Which of the following statements is correct ( )
   a. The reactions between acid and alcohol must be esterification reaction
   b. In the esterification reaction, carboxylic acid removes the hydroxyl of carboxyl and alcohol removes the hydrogen atom of hydroxyl
   c. Concentrated sulfuric acid is only playing a catalytic role in the esterification reaction
   d. In order to separate and purify the ester produced by the esterification reaction, the guide tube should insert into the level of saturated sodium carbonate solution below, and then separated through liquid-separation
9. Malic acid is a common organic acid, and its condensed structural formula is $HOOC-CH(OH)-CH_2-COOH$
   Which of the following reactions dose malic acid have ( )
   ①Reaction with sodium hydroxide solution
   ②Making the purple litmus red
   ③It can react with sodium and produce hydrogen
   ④It will react with acetic acid under the certain conditions, which is called esterification reaction
   ⑤It will react with ethanol under the certain conditions, which is called esterification reaction
   a.①②③ b.①②③④ c.①②③⑤ d.①②③④⑤
10. Which of the following statements is incorrect ( )
    a. The functional group of ethanoic acid is carboxyl, while the functional group of ethanol is hydroxyl
    b. Ethanoic acid can react with sodium carbonate and produce carbon dioxide, which indicating that the acidity of Ethanoic acid is stronger than the acidity of carbonic acid
    c. The reaction that ethanoic acid reacts with ethanol and produces ethyl acetate belongs to the acid-base neutralization reaction
    d. Ethyl acetate is a colorless oily liquid with a sweet smell, which is less dense than water and insoluble in water
11. Which of the following statements can indicate that ethanoic acid is weak acid ( )
    a. Ethanoic acid can't make phenolphthalein solution red
    b. Ethanoic acid can make purple litmus test solution red
    c. Ethanoic acid can react with sodium carbonate and produce carbon dioxide
    d. The hydrogen ion concentration of the 0.10M ethanoic acid solution is about 0.01M
12. What is the relative molecular mass of water that produced by the esterification reaction between acetic acid in which all

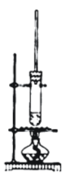
oxygen atoms are ^{18}O and ethanol in which the oxygen atom is ^{16}O ( )

a. 16 b. 18 c. 20 d. 22

13. The ethyl acetate produced from the reaction of ethanoic acid and ethanol often contains a small amount of ethanoic acid and ethanol, which of the following reagents is best chosen to remove the ethanoic acid and ethanol ( )
   a. Sodium hydroxide solution
   b. Saturated sodium carbonate solution
   c. Saturated sodium bicarbonate solution
   d. Dilute sodium carbonate solution

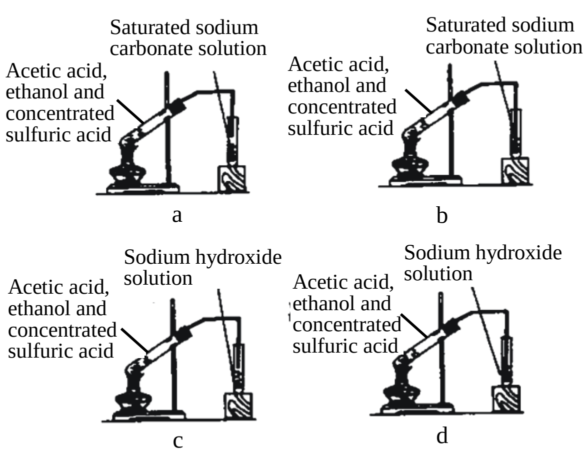
14. Which of the following statements about properties of ethanoic acid is incorrect ( )
   a. Ethanoic acid can react with carbonate solution and produce carbon dioxide because the acidity of acetic acid is stronger than the acidity of carbonic acid
   b. Ethanoic acid can react with sodium and produce hydrogen
   c. There is a carbon-oxygen double bond in the ethanoic acid molecular, so it can make bromine water color fade
   d. Ethanoic acid will condense into glacial crystal when the temperature is lower than 16.6degrees Celsius

15. The butyl acetate can be produced by the esterification reaction between 1-butanol and ethanoic acid with concentrated sulfuric acid as catalyst, and the reaction temperature is 115～125℃. The reaction device figure is shown below, which of the following statements about the experiment is incorrect ( )

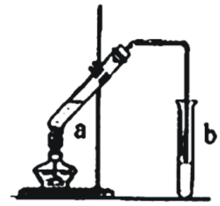


   a. The experiment cannot use water-bath heating
   b. The function of the glass tube is reflux condensation
   c. The water and sodium hydroxide solution are needed to wash when purifying butyl acetate
   d. Adding excess ethanoic acid will improve the conversion ratio of 1-butanol

16. Which of the following reaction equipments for producing ethyl acetate is correct ( )



17. A small amount of ethyl acetatecan be produced using the reaction equipment below



Answer the following questions:

(1) 2mL concentrated sulfuric acid, 2mL ethanoic acid and 2mL ethanol are needed to added to tube a respectively, what is the correct order of reagents addition and operation?

(2) Write the chemical equation and the reaction type of the reaction in tube a.

(3) What are the purposes of heating test tube?

(4) What are functions of saturated sodium carbonate solution in the test tube b? ( )
   a. Neutralizing the ethanoic acid and ethanol
   b. Reacting with ethanoic acid and absorbing partial ethanol
   c. It is facilitating the separating of ethyl acetate because the solubility of ethyl acetate in saturated sodium carbonate solution is less than in water
   d. It promotes the generation and productivity of ethyl acetate
   e. Why the guide tube is not inserted into the liquid level below in the test tube b? What experimental operations should apply to separate the ethyl acetate in the test tube b?

18. Milk will go sour after a long time, which results from a lot of lactose in the milk decomposed and produced lactic acid with the effect of microorganism. Lactic acid is also called 2-hydroxyl propionic acid, its condensed structural formula is

$$H_3C-\underset{}{\overset{OH}{\overset{|}{C}}}H-COOH$$

Answer the following questions:

(1) Write the names of functional groups of the lactic acid.

(2)Write the chemical equation of the reaction between lactic acid and enough sodium metal.

(3)Write the chemical equation of the reaction between lactic acid and sodium carbonate solution.

(4)With concentrated sulfuric acid as catalyst, two molecules of lactic acid can react and the product is annular structure. Write the condensed structural formula of the product.

(5)With concentrated sulfuric acid as catalyst, three molecules of lactic acid can react and the product is chains. Write the condensed structural formula of the product

Notes and references

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