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FLOW EXPERIENCE AND CHALLENGE-SKILL BALANCE IN E-LEARNING

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Abstract

Flow is an optimal experience resulting in intense engagement in the activity. People achieved flow state when they perceived balance between challenge of the activity and their skill to the activity. The concept of flow can be used to explore students' learning performance in e-learning environment. The current research aims to empirically explore the influence of challenge-skill balance on the flow experience and the influence of flow experience on learning satisfaction and learning performance in e-learning environment. The current research conducted a quasi-experimental design with questionnaire survey and carried out an electroencephalography (EEG) analysis, a psychophysiological method. The empirical survey results have shown that challenge-skill balance is an antecedent factor affecting learners' flow experience. Once learners reach flow experience, their learning performance and learning satisfaction would get improved. Besides, the current research also found that flow experience is relative with learners' attention measured by EEG brainwave signal. Learners' perception of challenge-skill balance would influence their attention in e-learning activities. The current research is also in the pioneering position that using non-medical purpose EEG device in e-learning research.

Keywords: Flow, E-Learning, Electroencephalography (EEG), Learning Performance.

1 INTRODUCTION

E-learning, which is an efficient and effective approach for learners to acquire knowledge, has flourished since the early 1990s with the progress of information and network technology. Although e-learning has been prevailing in recent years and its potential benefits are quite significant, there are still a number of challenges and limitations for e-learning implementation (Cantoni et al., 2004). Generally, in the context of traditional learning, students' learning condition can be directly observed by teachers; however, e-learning is not a face-to-face approach, so that it will be difficult for teachers to realize about students' learning condition in the e-learning context.

One of the most salient changes in the field of education is the new paradigm shift from teacher-centered to learner-centered education. Along with this paradigm shift, learning is no longer viewed as a one-way process, which means that learners can be more active to make a suitable response to the questions and activities as well as completely engages in the learning process (Huffaker & Calvert, 2003). To explore students' learning condition in e-learning environment, academics take the concept of flow into account.

Flow is originally proposed by Csikszentmihalyi as an optimal experience resulting in intense engagement, distorted sense of time, and heightened motivation (Csikszentmihalyi, 1990). Novak et al. (2000) indicated that when people get into the state of flow, they are completely immersed in the activity. Flow experience brings in the feeling of pleasure and enthusiasm. People increase their motivation to be involved in the activities like exercise, gaming, shopping, web use, and learning when they are with flow states. Previous studies have applied flow theory into various fields. The current research concentrates on the theme of learning.

The primary concept of flow is the balance between challenge and skill (Csikszentmihalyi, 1990). People would devote themselves to what they are doing, feeling joyful and delight if people's skills are well enough to deal with the challenge of activity. When students' skills can match the challenge of learning content, they may have achieved flow state and it turns out the enhancement of learning performance and learning satisfaction.

Some previous studies have measured flow by self-report questionnaire survey. Subjects are asked to recall their flow experience when engaging in the activities. Nevertheless, flow is a changeable state rather than just an overall state (Pearce et al., 2005). Flow may appear in the process of activity during a short period of time. Self-report flow measurement scales are confronted by an issue that people perceive different affective states in different time span. Self-report flow experience scales report individuals' feeling of the whole activities rather than a specific time point. This will be a shortcoming when researchers hope to realize the impact of a specific circumstance to individuals' flow states. To overcome this issue, the current research adopted Electroencephalography (EEG), a psychophysiological method, to examine learners' affective states during learning process.

Traditional EEG device has been broadly used for health and medical purposes. It seems that this kind of device is too complicated to use for educational research. However, with the advancement of technology, brain-computer interface (BCI) companies have provided simple and low-cost EEG device. The present research attempts to use a low-cost EEG headset to record brainwave signals to observe learners' attention during e-learning process.

The research aims to examine learners' flow experience in e-learning and explore the relationship between learning outcome and flow experience through an analysis of psychophysiological data as well as self-reported questionnaire survey. We investigated if the challenge-skill balance can really have a positive effect on flow experience. The traditional questionnaire asks subjects to report their affective states within e-learning after they complete the learning process. The EEG brainwave headset can measure subjects' affective states during the whole process of e-learning. The real-time affective states measured by EEG brainwave headset can help researchers to realize the flow experience from psychophysiological approach.

2 LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

2.1 Flow and Challenge-Skill Balance

During a specific activity, people might have the feeling of control and complete focus, and with a high level of enthusiasm and fulfillment. This kind of feeling is named as flow experience, originally introduced by Mihaly Csikszentmihalyi, a professor of psychology at the Claremont Graduate University. Csikszentmihalyi (1990) revealed that flow is an optimal experience resulting in intense engagement, distorted sense of time, and heightened motivation. Once people are in the flow state, they are fully engaged in what they are doing and feel pleasure (Novak et al., 2000).

Originally, the initial models of flow provided by Csikszentmihalyi mainly focused on the challenge-skill balance aspect. The flow state can be represented as a “channel”, happening in the condition of challenge-skill balance. Csikszentmihalyi (1975) proposed the three channel model of flow in order to discriminate human affective states (i.e., flow, anxiety, and boredom) in different activities. This figure indicates that task challenges and skills people perceive with will influence their current affective states. Flow state appears when perceived challenge and perceived skill are balance. If the challenge is beyond people’s skill, ones might come to a state of boredom; on the other hand, if the challenge increases but one’s skill cannot afford to meet the challenge, the overwhelming activity generates anxiety. The area which belongs to a balance between challenge and skill can be referred to as the flow zone.

The flow channel demonstrates flow ranging from low to high complexity (Pearce et al., 2005). It would be better to say that if the person involve in a very little challenging task along with an identical low skill, the flow state still produce, and vice versa. This three status model of flow was soon refined into two further versions: a four status model which separate apathy from flow to describe the situation of low skill and little challenge (Csikszentmihalyi, 1988) and an eight affective status model of arousal, anxiety, worry, apathy, relaxation, boredom, control, and flow (Massimini & Massimo, 1988). All these models need challenge and skill beyond the threshold for flow to take place (Massimini & Massimo, 1988).

Previous studies have focused on challenge-skill balance proposed by Csikszentmihalyi (1975). Hoffman and Novak (1996) proposed a model of flow state for users to navigate online environments. In the model, challenge-skill pairing was proposed as an antecedent of flow. Sweetser and Wyeth (2005) created a model of game flow which took challenge-skill balance into account. Shin (2006) argued that learners would achieve flow experience when they perceived the balance of challenge and skill. Thus, we propose the following hypothesis:

H1: Challenge-skill balance has a positive effect on flow.

2.2 Flow and e-Learning Performance

The origins of the term e-learning is uncertain, but it is said that the term more likely appeared during the 1990s (Choi et al., 2007; Lee et al., 2009). In a broad sense, some researchers regard e-learning as an approach for transmitting learning materials though electronic media like Internet, Intranets, Extranets, satellite broadcast, audio/video tape, interactive TV, and CD-ROM (Engelbrecht, 2005; Govindasamy, 2001). However, in a narrow sense, e-learning sometimes also defined as a web-based learning which utilizes network technologies to communicate, collaborate, transfer knowledge, and facilitate learning anytime and anywhere (Kelly & Bauer, 2004; Raab et al., 2001). Sun et al. (2008) suggested that e-learning is a web-based system, making information or knowledge available to users or learners without considering time and area restrictions. In this research, we are in a broad view to define e-learning as digital learning materials that learners can learn on their own through electronic ways such as learning video clips or others.

Flow can emerge from any kinds of activities like sports, games, and web use. The concept of flow is also widely used in learning, talking about flow in learning environment and the influence of flow on learning outcomes. Pearce et al. (2005), for example, used the constructs of flow to explore learning in

an online environment, and suggested that flow can be viewed as a changeable process rather than just an overall state during learning. As for the learning outcomes, Hwang et al. (2012) designed an effective learning system for students, and found the proposed game approach promote students' flow experiences in web-based problem-solving activities. Besides, flow experience was used to create the benefits of e-learning in technological companies as well (Ho & Kuo, 2010). Ho and Kuo (2010) indicated that flow experience has a positive effect on learning outcomes. In addition, several studies have applied the concept of flow in cooperative learning to examine whether learners can experience flow and enhance learning in groups (Admiraal et al., 2011; Raphael et al., 2012; van Schaik et al., 2012). Most of those studies provided a game-based learning for students because this kind of approach can arouse their interest and learning motivation.

Flow experience positively affects students' satisfaction to learning (Yi et al., 2007). Shin (2006) confirmed that flow is a significant predictor of course satisfaction in online learning. Rossin et al. (2009) investigated that the relationship between students' experiences of flow and learning outcomes. Joo et al. (2011) also suggested the impact of learning flow on learners' satisfaction. Based on the above discussion, we proposed the following hypothesis:

H2: Flow experience has a positive effect on learning outcomes.

2.3 Measuring Flow by EEG Brainwave Signal

Electroencephalography (EEG) is the process of recording brainwave activity and has been described as a "window on the mind" (Nunez & Srinivasan, 2006). In the research of brain-computer interface (BCI), EEG is one type of psychophysiological measurement, investigating the relationships between mental and bodily processes. Typically, EEG is measured by recording the voltage of electrodes on the scalp and those electrodes are placed in normal positions distributed over head (Nacke et al., 2011).

EEG is usually described in terms of frequency band, such as alpha (7.5-11.75 Hz), beta (13-29.75 Hz), theta (3.5-6.75 Hz), delta (0.5-2.75 Hz), and sometimes gamma (31-49.75 Hz). Alpha power usually arises when people are awake and feel relaxed, and has been linked to mental idleness (Pfurtscheller et al., 1998). Beta power often appears in the frontal cortex, connecting closely with cognitive processes, such as information processing, problem solving and decision making (Ray & Cole, 1985). Theta wave is associated with meditation, memory recall, emotions, creativity, intuition, and sensations (Aftanas & Golocheikine, 2001). Delta wave seems to be connected to unconsciousness and deep sleep (Cacioppo et al., 2007).

EEG has already been widely used in health and medical applications, such as epileptic seizures (Mormann et al., 2000) and sleep disorder research (Kupfer et al., 1978). In recent years, researchers has applied EEG on other fields, such as neuromarketing, brain-computer interface, and gaming. For example, Ariely and Berns (2010) expressed that neuromarketing would be a potential way for business to develop marketing strategies in the near future. Some research topics related to brain-computer interface talking about people use EEG activity to control external devices like robots, virtual environment, or spelling devices (Guger et al., 2009; Wolpaw et al., 2002). In the research of gaming, Russoniello et al. (2009) analysed players' EEG brainwave signal and revealed that playing casual games helps players to be in a good mood.

Since EEG is a psychophysiological measurement which connects closely with one's affective states, some researchers have investigated the relationship between EEG and flow experience in gaming (Chanel et al., 2011; Klasen et al., 2012; Nacke et al., 2011). However, little attention has been given to the relevance of EEG and flow in e-learning environments. To broaden the view of flow concept on e-learning, the current research measured learners' affective states by recording EEG signals to explore if flow experience could have influence on learning outcomes.

3 EMPIRICAL STUDIES

The research aims to find out whether learners may have achieved flow experience when they perceive the challenge-skill balance during the activity of e-learning. Also, we further explore the effect of flow

states on learning performance and learning satisfaction. The current research conducted a questionnaire survey and carried out an electroencephalography (EEG) analysis, a psychophysiological method which provided a reliable and useful measurement of learner's affective states. The independent variable, challenge-skill balance, was an important antecedent to predict flow experience. The dependent variables, learning satisfaction and learning performance, were the consequences of flow experience. Table 1 listed the methods and purposes of the current research.

Study	Method	Purpose
Study 1	Questionnaire survey	To investigate whether the antecedent, challenge-skill balance, would really have an effect on flow experience by questionnaire survey. The effect of flow experience on learning performance and learning satisfaction were also revealed in this study.
Study 2	EEG brainwave measurement	To explore the relationship between flow experience and learners' brainwave signal.

Table 1. Empirical studies of the current research

As shown above in Table 1, we conducted two studies. In study 1, we use traditional paper-and-pencil questionnaires to measure participants' flow experience on the e-learning process. According to the original flow concept, challenge and skill balance that people perceive in activities play a critical role to achieve flow experience. Hence, study 1 sets the context of e-learning in order to discover the effect of challenge-skill balance on learners' flow states. The connection of flow experience to learning performance and satisfaction are also investigated in study 1.

Furthermore, to understand learners' engagement in the whole process of e-learning, a brainwave headset was used in study 2 to make a record of psychophysiological signal. Since brainwave attention can be regarded as an important index to know the learners' engagement, we assumed that brainwave attention correlated closely with flow experience during the activity of e-learning. The main purpose of the study 2 is to figure out the relationship between flow experience and brainwave attention.

3.1 Study 1

3.1.1 Participants

Participants of study 1 were college students enrolled in a class of introduction to computers. They already had essential knowledge and learning experience on using Microsoft Office software. All subjects voluntarily joined the study 1 and were informed of their right to decline. Subjects needed to spend about one and a half hour, including the time for exercise, to complete the study. Among the 189 respondents who voluntarily participated in the survey, 41 were eliminated because of incomplete responses. The study analysis was based on the remaining 148 usable responses (38.5% male and 61.5% female). In terms of the age of participants, 93.9% subjects were in nineteen or twenty years. The average age of respondents was 19.54 years with the standard deviation of 0.74.

3.1.2 Procedure

In the beginning, this study asked subjects to take a pre-learning quiz. Then, subjects were asked to finish three e-learning lessons. Each lesson included learning material about Excel operation with contents from easy, middle to difficult. After each learning lesson, subjects were requested to operate on the spot and make some exercise. Then, they were asked to fill out the measurement items about challenge-skill balance and flow experience. The procedures repeated for each of the three lessons.

After completing the three e-learning lessons, subjects were asked to present their satisfaction to the whole e-learning process by paper-and-pencil questionnaire. Then, they were asked to take the post-learning quiz, which comprised the same questions in the pre-learning quiz. Both of the pre-learning and post-learning quiz included twelve multi choice questions (four questions each for easy, middle, and difficult levels). All answers of the twelve questions were included in the three level e-learning lessons. The improvement in quiz scores was used to reveal subjects' learning performance.

When all the procedures of this study were finished, a small souvenir, worth approximately USD 4, was given to each respondent.

3.1.3 Measures

The study adopted flow experience scale by Shin (2006) to measure learners' flow experience dimensions of enjoyment, telepresence, focused attention, and time distortion. There were three items for each dimension. The measurement scale of Shin (2006) is adapted from previous flow research (Yagner et al., 1996; Steuer, 1993; Shin 2005; Novak et al., 1998; Skadberg and Kimmel, 2004). Nevertheless, the statements of measurement items of "engagement" dimension of flow in Shin (2006) were not appropriate for the present study. Thus, we adopted "involvement" as a replacement based on Hoffman and Novak (1998)'s conceptual model. The dimension of involvement was measured using three items developed by Saxena, Khurana, Kothari and Jain (2003). All of the items in this study were a 7-point Likert scale with a score of 1 indicating "strongly disagree" and 7 "strongly agree". A subject with a high score is more likely to achieve flow experience during the process of e-learning.

As for challenge-skill balance measurement, subjects were asked to present the balance of challenge and skill in a 7-point scale from -3 (too easy) to 3 (too difficult). The neutral score (0 point) was regarded as challenge-skill balance, while positive or negative scores were regarded as unbalance. The question about challenge-skill balance was presented to subjects across different challenge levels, so we can know if the learning material is too hard, too easy, or moderate for learners. To assess learning satisfaction, the study 1 adopted six items of 7-point Likert scale used by Shin & Chan (2004).

3.1.4 Reliabilities, validation and common method variance

The study 1 calculated Cronbach's alphas to measure the reliability of the scales. The Cronbach's alphas of enjoyment, telepresence, focused attention, involvement, time distortion and satisfaction were .94, .85, .94, .82, .96 and .88, respectively. All of the reliability values exceeded 0.70, which were well within the acceptable range.

The study accessed convergent validity by examining the average variance extracted (AVE) of each dimension. The results showed that all AVE values in this study were well above the value of 0.5 suggested by Fornell and Larcker(1981). Therefore, we confirmed the convergent validity of the measurement scales.

Discriminant validity refers to the extent to which evaluations of different constructs are unique from each other (Bagozzi, 1981).The discriminant validity was examined through correlation among measurement scales. As shown in Table 2, the square root of AVE in each measurement scale is greater than correlation coefficients, indicating that the discriminant validity has been accepted.

	Cronbach's alpha	1	2	3	4	5	6
1. Enjoyment	.94	.79					
2. Telepresence	.85	.75**	.78				
3. Focused Attention	.94	.68**	.70**	.77			
4. Involvement	.82	.54**	.61**	.47**	.74		
5. Time Distortion	.96	.69**	.62**	.74**	.52**	.79	
6. Learning satisfaction	.88	.54**	.57**	.44**	.57**	.49**	.71

Note: ** $p < 0.05$; values in bold are square root of AVE

Table 2 Cronbach's alpha, Correlations and square root of AVE values

Given that the data of this study were collected simultaneously and used the same instrument, it was necessary to address the possibility of the common method variance (Gefen, Karahanna & Straub, 2003). Therefore, this study adopted Harmon's one-factor test (Podsakoff & Organ, 1986). We performed an exploratory factor analysis of all 21 items (15 for flow experience and 6 for learning satisfaction) in our survey and extracted six factors with eigenvalues greater than 1. 79.22% of the variances were explained by the 6 factors, and the first factor accounted for 42.21% of the variance

only. Thus, it may be concluded that the measurement scales were not affected by the common method variance.

3.1.5 Results

The study 1 included three e-learning lessons with easy, middle and difficult learning materials. Thus, we conducted data analysis for each lesson respectively. The average scores of overall flow experience in seven point scales were 4.96 (SD=0.87), 4.46 (SD=1.06), and 4.60 (SD=1.16) for easy, middle and difficult lessons. Flow experience in easy level lesson is higher than middle and difficult lessons. The low flow experience in the middle and difficult level lessons may be owing to difficulty of leaning materials. For most subjects, the middle and difficult level e-learning lesson were too difficult. The average score of pre-learning quiz (four multi choice questions) was 1.14 (SD=1.25) for easy level lesson, 0.80 (SD=0.89) for middle level lesson, and 0.46 (SD=0.80) for difficult level lesson.

In the easy level e-learning lesson, subjects' average flow is 4.66 (SD=0.97) in 7-point scale. The average score of pre-learning quiz (four multi choice questions) was 1.14 (SD=1.25). The average score of post-learning quiz (the same multi choice questions) was slightly improved to 2.89 (SD=0.93).

To explore the impact of challenge-skill balance on flow experience, we divided all participants into balance and unbalance groups, and performed t-test to identify the difference of flow experience between the two groups. The t-test results revealed significant difference of flow experience existed between balance and unbalance groups in the easy lesson ($t=5.55$; $p<.01$). The results confirmed that learners who perceived challenge-skill balance might achieve higher flow experience (Mean= 4.96; SD=0.87) than ones who perceived unbalance (Mean=4.12; SD=0.91).

In the middle level e-learning lesson, the average flow is 4.25 (SD=0.98) in 7-point scale. The average score of pre-learning quiz (four multi choice questions) was 0.80 (SD=0.89). The average score of post-learning quiz (the same multi choice questions) was improved to 2.41 (SD=1.12). The t-test analysis result is significantly in flow experience ($t=2.76$; $p=.00$) between challenge-skill balance (Mean= 4.46; SD=1.06) and unbalance groups (Mean= 4.03; SD=0.85).

In the difficult level e-learning lesson, the average flow is 4.24 (SD=1.03) in 7-point scale. The average score of pre-learning quiz (four multi choice questions) was 0.46 (SD=0.80). The average score of post-learning quiz (the same multi choice questions) was improved to 2.03 (SD=1.29). Besides, only 33 subjects among the 148 ones reported they are in the state of challenge-skill balance. The remained 115 subjects reported that the learning contents were too hard for themselves. There also had a significant difference in flow experience ($t=2.06$; $p=.04$) between balance (Mean= 4.60; SD=1.16) and unbalance groups (Mean= 4.14; SD=0.97).

To sum up, there are significant difference in flow experience between challenge-skill balance and unbalance groups in all three e-learning lessons of easy, middle, and difficult levels. Challenge-skill balance subjects reported higher flow experience than unbalance ones. The results support the hypothesis 1 that challenge-skill balance will have a positive effect on flow.

Now that we are sure that challenge-skill balance really has an effect on learners' flow experience during e-learning, the next step is to reveal the impact of flow experience on learning outcomes. The descriptive statistics in Table 3 tell us about the average score of pre-learning quiz and post-learning quiz, contain four questions in each lesson. If one question was correctly answered by a subject, we counted one point she or he got. Obviously, we can find that the mean score of pre-learning quiz in the easy level lesson (Mean=1.14, SD=1.25) is higher than that in the middle (Mean=0.80, SD=0.89) and difficult (Mean=0.46; SD=0.80) level lesson. The low average score of pre-learning quiz in the middle and difficult level lesson mean that the middle and difficult level e-learning lesson were too difficult for most of the subjects. Nevertheless, through the e-learning process, the subjects' learning performance really has a great improvement, especially in the middle and difficult lessons. The quiz scores improved 1.75, 1.61, 1.57 for easy, middle, and difficult level e-learning lesson, respectively.

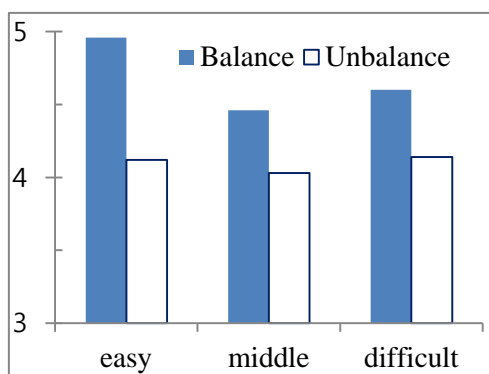


Figure 1. Flow experience between balance and unbalance groups

	Flow	Pre-learning quiz	Post-learning quiz	Learning performance
Easy level lesson				
Mean	4.96	1.14	2.89	1.75
S.D.	0.97	1.25	0.93	1.48
Middle level				
Mean	4.46	0.80	2.41	1.61
S.D.	0.98	0.89	1.12	1.24
Difficult level				
Mean	4.60	0.46	2.03	1.57
S.D.	1.03	0.80	1.29	1.39

Table 3. Learning performance among three level lessons

The study 1 examined the relationship between flow experience and learning outcomes by correlation analysis. The correlation analysis results indicated that flow was positively correlated with learning performance in all three e-learning lessons of easy ($r=.37$; $p=.00$), middle ($r=.20$; $p=.01$) and difficult level ($r=.17$; $p=.04$).

Furthermore, the study 1 divided subjects into two groups based on their performance improvement. We conducted t-test analysis to investigate the difference of flow between these two groups. The results revealed significant differences of flow in the easy ($t=2.56$; $p<.01$) and difficult ($t=2.56$; $p<.01$) level e-learning lesson. Nevertheless, there was no significant difference in flow in the middle ($t=1.37$; $p=.17$) level learning lesson between performance improved and unimproved groups. The results revealed that subjects with improved performance also experienced higher level flow states than ones with unimproved performance. This may serve as an evidence for the connection between flow states and learning performance.

	Group 1: Performance improved	Group 2: Performance unimproved	t value	p value
Flow (easy level)	N=111	N=37		
Mean	4.79	4.27	2.559	
S.D.	0.88	1.13		($p<.01$)
Flow (middle level)	N=119	N=29		
Mean	4.30	4.02	1.372	
S.D.	0.96	1.07		($p=.17$)
Flow (difficult level)	N=110	N=38		
Mean	4.37	3.88	2.558	
S.D.	1.03	0.94		($p<.01$)

Table 4. Flow between performance improved and unimproved groups

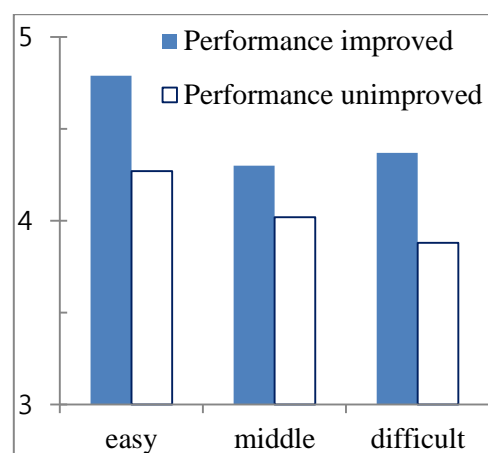


Figure 2. Flow and performance improvement

The study 1 also conducted a correlation analysis to reveal if flow is an antecedent for satisfaction. Since the study 1 measured only satisfaction of the whole e-learning process, we merged flow experience of three e-learning lessons as the aggregate flow of the whole e-learning process. In addition, the correlation of learners' aggregate flow and performance of the whole e-learning process, instead of the flow and performance in each lesson, were examined. The results revealed that aggregate flow was positively correlated with learning performance ($r=.28$; $p<.01$) and learning satisfaction ($r=.72$; $p<.01$).

3.1.6 Discussion

According to statistical analysis mentioned above, the study showed that challenge-skill balance was closely correlated with flow experience, and the flow experience lead to better learning outcomes. Significant difference of flow experience was found between challenge-skill balance and unbalance groups; balance group acquired a higher flow experience than unbalance group. When learners perceived that the challenge of learning content was beyond or below their original skill, they could not get into flow state during e-learning. The result is consistent with the idea of Csikszentmihalyi (1975), Hoffman and Novak (1996) and Shin (2006) who considered that challenge-skill balance plays a critical role to achieve flow experience. Thus, our hypothesis 1, challenge-skill balance has a positive effect on flow experience, is supported.

In addition, the study 1 examined the relationship between flow experience and learning outcomes, revealing that flow experience positively correlated with learning performance and learning satisfaction. The study 1 also found that subjects with improved performance had a higher level of flow experience than ones with unimproved performance. These findings verify hypothesis 2 that flow experience has a positive effect on learning outcomes.

Questionnaire survey can measure subjects' self-report subjective flow experience only at the moment when completing each e-learning lesson. Nevertheless, flow state change from time to time. In study 2, we use a psychophysiological method, EEG recording, to explore learners' attention in all moment of e-learning. The study 2 aims to figure out the relationship between flow experience measured by questionnaire survey and learners' attention measured by brainwave signal. Further discussion will be presented in the next section and let us get nearer to the real condition of psychophysiological state in different levels of difficulty during e-learning.

3.2 Study2

3.2.1 Participants

The study 2 focuses on the relationship between flow experience and the learners' attention measured by brainwave signal. Twenty subjects, including 10 males and 10 females, were invited to participate in the study 2. All of them were college and graduate students, with age ranged from 19 to 27 years ($M=23.75$, $SD=3.25$). The participants voluntarily participated in this e-learning course and were informed their right to decline. All participants of study 2 were not the same as ones of study 1.

3.2.2 Procedure

The experimental procedure of the study 2 was as same as study 1, except using a brainwave headset to measure subjects' attention. Participants entered the laboratory individually and listened to a briefing of the experimental procedure. Then, participants were led to a laptop computer and asked to wear the brainwave headset. After wearing the brainwave headset, the study 2 asked participants to take three e-learning lessons with easy, middle and difficult level e-learning materials. In the meantime, their brainwave signals were recorded as well. When they completed each e-learning lesson, subjects were asked to fill out questionnaires of challenge-skill balance and flow experience. A reward, worth approximately USD 4, was given to each subject for their participation in the study.

3.2.3 Measures

The study 2 applied the same paper-and-pencil questionnaires used in study1 to measure subjects' challenge-skill balance, flow experience, and learning satisfaction. As for the measurement of EEG, we used the "Mindset" EEG headset developed by Neurosky Inc, as show in Figure 3, which collected 8 frequency band of brainwave signal, consisting of high alpha (10~11.75Hz), low alpha (7.5~9.25Hz), high beta (18~29.75Hz), low beta (13~16.75Hz), mid gamma (41~49.75Hz), low gamma (31~39.75Hz), delta (0.5~2.75Hz), and theta (3.5~6.75Hz). The brainwave data provided by

the Neurosky headset also includes an attention indicator derived from the 8 bands EEG value to reveal subject's mental focus (Neurosky, Inc, 2009). The value range of attention indicator is from 0 to 100. The study 2 adopted it for further data analysis.

3.2.4 Results

Table 5 revealed that brainwave attention scores were significantly different among different level e-learning lessons. Subjects' attention gradually increased along with the progress of e-learning and reached the peak in the difficult level e-learning lesson. Subjects' attention level in difficult level e-learning lesson is higher than middle. Middle is higher than easy lesson. The more difficult the lesson, the more attention the subjects held.

Attention	Easy Lesson	Middle Lesson	Difficult Lesson	ANOVA analysis
Mean	47.13	47.78	48.53	F=12.76
S.D.	19.19	17.73	20.73	p<.001

*p<0.05; **p<0.01

Table 5. Brainwave attention of three lessons



Figure 3. EEG headset used in study 2

The relationship between attention and flow experience revealed that the flow experience was positively related to the brainwave attention in the easy level e-learning ($r=.54$, $p=.02$). However, no significant correlation were found between flow experience and attention in the middle ($r=.09$, $p=.72$) and difficult level lessons ($r=.37$, $p=.11$).

Having seen that flow experience measured by questionnaire correlates with attention measured by EEG brainwave signal, we may further observe the relationship between attention and balance between skill and challenge. The study 2 divided subjects into two groups based on their skill-challenge balance. Like the way of grouping in study 1, the grouping criterion was based on learners' feeling about each challenge level. The participants would choose neutral score (0 point) as their answer when they thought their original skill had a good fit with the learning challenge. In this condition, they would be categorized as balance group and might have achieved the state of flow experience. We conducted t-test analysis to investigate the difference of subjective flow experience and brainwave attention between these two groups. As showed in Table 6, the results revealed significant differences of flow ($t=3.11$, $p=.01$) and attention ($t=2.57$, $p<.01$) in the difficult level e-learning lesson. Nevertheless, there was no significant difference in flow and attention in the middle ($t=-0.49$, $p=.63$ for flow; $t=0.34$, $p=.94$ for attention) and easy ($t=1.70$, $p=.11$ for flow; $t=0.62$, $p=.54$ for attention) level learning lesson between skill-challenge balance and unbalance groups.

The correlation analysis result revealed that attention value was negatively related to unbalance between skill and challenge in difficult level e-learning ($r= -.48$; $p=.03$). The correlation analysis result revealed that attention value was negatively related to unbalance between skill and challenge in difficult phase. The more balance, the more attention. Subjects' attention increased if they perceived more balance (less unbalance) between skill and challenge during e-learning. This may serve as an evidence for the linkage of skill-challenge balance to flow and attention. Nevertheless, the correlation coefficients were negative but not significant in easy ($r= -.25$, $p=.30$) and middle ($r= -.21$, $p=.39$) level e-learning.

	Group 1: Balance	Group 2: Unbalance	t value	p value
Flow in easy level lesson	N=7	N=13		
Mean	4.87	4.01	1.707	$p=.105$
S.D.	1.10	1.06		

Attention in easy level lesson	N=7	N=13		
Mean	48.40	46.16	0.623	$p=.541$
S.D.	8.13	7.39		
Flow	N=13	N=7		
Mean in middle level lesson	4.16	4.33	-0.487	$p=.632$
S.D.	0.82	0.65		
Attention in middle level lesson	N=13	N=7		
Mean	48.19	47.27	0.339	$p=.739$
S.D.	4.52	7.70		
Flow in difficult level lesson	N=4	N=16		
Mean	5.05	3.88	3.111	$p=.013^*$
S.D.	0.41	1.26		
Attention in difficult level lesson	N=4	N=16		
Mean	59.76	46.23	2.571	$p=.007^{**}$
S.D.	13.65	7.46		

Table 6. Difference between challenge-skill balance and unbalance in difficult level e-learning

Moreover, we divided all the subjects into two groups of novice and expert based on their pre-learning quiz score. The study 2 considered subjects as experts if they correctly answer more than a half of the twelve questions. In contrast, the other subjects were categorized as novice when they did not correctly answer a least a half of the questions. This study compared novices' and experts' attention level to each e-learning lesson by t-test analysis. The t-test results found significant differences of learning attention in between easy and difficult level e-learning lesson. Novices' attention value was higher than experts' in easy level lesson. However, in difficult level lesson, novices' attention level was lower than that of experts. When the learning material became harder, experts' attention risen while novices' attention descent. Novices paid attention to easy level lesson and lose their attention when they faced too difficult learning materials. In the easy level lesson, experts' attention was quite low. However, experts' attention level dramatically increased in difficult level e-learning lesson. Thus, experts paid attention to difficult level lesson, while novices paid attention to easy level lesson. The results may serve as an evidence for the connection between skill-challenge balance and attention.

	Group 1: Novice (n=16)	Group 2: Expert (n=4)	t value p value
Attention in easy level lesson			
Mean	48.79	39.58	$t=2.47$
S.D.	6.74	6.38	$p=.02^*$
Attention in middle level lesson			
Mean	47.66	48.70	$t=-0.32$
S.D.	4.50	9.95	$p=.75$
Attention in difficult level lesson			
Mean	46.38	59.19	$t=-2.55$
S.D.	7.80	12.84	$p=.02^*$

Table 7. Attention of novices and experts

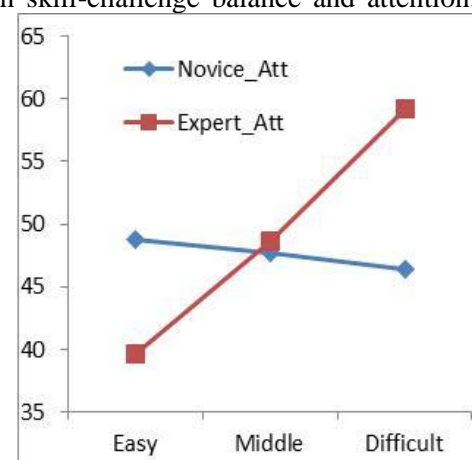


Figure 4. Attention of novices and experts

Figure 4 helps to understand the trend of attention scores in each e-learning lesson for novices and experts. This result can explain the reason why some learners do not concentrate on learning. Learners who are experts might feel boring if the learning content is too easy for them. Therefore, expert learners will not focus on the easy learning content and their attention will not on the easy learning materials. The similar issue happen to novices during difficult level learning. Too difficult learning content perhaps cause novices to feel anxious, so their attention will reduce when the learning materials become hard.

In addition, the study 2 conducted correlation analysis to examine the relationship between learning outcomes and brainwave attention. The results showed that learning performance was positively correlated with attention in difficult phase ($r=.54$; $p=.03$). Nevertheless, no statistical significance was

found in easy ($r=.01$, $p=.96$) and middle ($r=-.16$, $p=.56$) level e-learning lessons. As for learning satisfaction, it is not significantly correlated with learners' attention ($r=.16$, $p=.51$).

3.2.5 Discussion

The results of study 2 showed that flow experience has a positive correlation with learners' attention in easy phase, but not in middle and difficult phases. Also, the challenge-skill balance still played an important role to affect the subjects' learning attention. Learners' who perceived challenge-skill balance would have much higher attention than those perceived unbalance. Unbalance between challenge and skill is negatively correlated with attention, which represents the more unbalance between challenge and skill that learners perceive, the less attention they will have.

Moreover, the study 2 divided the participants into experts and novices. These two kinds of learners possessed with different learning attention in easy and difficult phases. Experts' attention was pretty low in easy phase, but their attention dramatically increased during difficult level lesson learning. For novices, their attention was pretty high in easy phase, but their attention dramatically decreased during difficult level lesson learning. Accordingly, it seems reasonable to conclude that providing learners with a suitable learning material is necessary, so that they can concentrate on what they are learning in e-learning environment. The statistical analysis result also revealed that learners with high attention would also have better learning performance improvement.

4 GENERAL DISCUSSION

This research aims to empirically investigate the phenomenon of flow in the e-learning environment. The links among challenge-skill balance, flow experience and learning outcomes were examined thorough a questionnaire survey and a psychophysiological method, EEG recording. Observations in study 1 have shown that challenge-skill balance is an antecedent factor affecting learners' flow experience. Besides, once learners reached flow experience during e-learning, both of their learning performance and learning satisfaction would get improvement. Such the results support our hypotheses 1 and 2.

In the study 2, we figure out the relationship between flow experience and attention measure by EEG brainwave. Since attention can be regarded as an index to address the state of flow, this study recorded all the subjects' brainwave for data analysis. The results reflect that flow experience really have a positive correlation with learners' attention. Also, a further result shows that learners' perception of challenge-skill balance will influence their attention when they are learning.

4.1 Implications for theory and practice

The current research contributes to the extant literature and practice in several ways. First, the current research confirms that challenge-skill balance is an essential antecedent to achieve flow experience. Although some previous studies (Hoffman & Novak, 1996; Mathwick & Rigdon, 2004; Sweetser & Wyeth, 2005) had proposed and investigated such relationship, these previous studies did not pay attention to the context of e-learning. In the current research, challenge-skill balance was examined in e-learning environment. Additionally, positive correlation between flow experience and learning outcomes were also found in this research. Thus, we can conclude that learners with higher flow experience will lead to better learning performance and satisfaction during e-learning.

Another contribution of this research is to conduct flow research by using psychophysiological method, EEG brainwave signal recording. The previous research by Pearce et al. (2005) proposed that flow experience is a dynamic process rather than just an overall state. Hence, just doing questionnaire survey for flow measurement will not exactly get the real condition of flow experience when learners participate in e-learning lesson. This study suggests that EEG recording is another approach to measure flow experience instead of traditional paper-and-pencil questionnaires. Through the brainwave data analysis, the current research indicated that flow experience was positively correlated

with learners' attention. In addition, this study examined the relationship between challenge-skill and attention, and found that learners' attention decline when their original ability did not match the challenge of learning material. Learners will only gain attention in e-learning environment if they perceive the balance of challenge and skill. We also made a further discussion about novices and experts' different attention in e-learning. Experts' attention becomes higher when they face the advance learning content. However, novices' attention is high in easy level learning materials, but with a decrease in difficult level learning materials.

Besides, the research provides an approach to realize the influence factors of learning performance. It is necessary for educators or e-learning platform developers to design suitable learning materials according to learners' aptitude. The best way to do is to offer various levels of difficulty that learners can choose on the basis of their ability. In short, novices should select an easy content for learning because too difficult content may lead to attention decline. With the advancement of their knowledge and ability, they can choose the next level learning content. As such, they will achieve flow experience easily and be active to keep enthusiasm in learning. In contrast, experts are advised to give them a little bit difficult contents, so that they can concentrate on learning materials. Following the principle of this finding will make learning more meaningful and enjoyable.

4.2 Limitations and suggestions for future research

In light of our findings, certain limitations and suggestions for future studies should be considered. First, the current research focused on challenge-skill balance as an important antecedent influencing flow experience in e-learning environment. Nevertheless, lots of factors like instructional factors and platform relative factors are also recommended to be considered in future studies.

Secondly, this study used a psychophysiological method to measure learners' flow experience. The indicator of attention provided by Neurosky Mindset EEG headset is not a precise indicator. Therefore, the important next step is to analyse raw data of brainwave including alpha, beta, delta, etc. to further explore the relationship between flow experience and brainwave activity in e-learning. Thus, future studies will be able to understand flow experience in detail and applied the conception of flow into other fields. Psychophysiological measures such as brainwave recording and eye tracking are now available recently. These measurement tools can help us discover more unexpected phenomena for future studies of e-learning activities.

Csikszentmihalyi (1975) argued that people will be in the state of anxiety if their skills are lower than the challenge they faced. Nevertheless, in education practice, advanced learning materials may be necessary to improve learners' knowledge and ability. Flow state could not be achieved because of the hardness of advanced learning materials. Thus, it would be an important issue for practice to improve learning performance of learners who are not in flow state. Further studies might focus on the learning performance of low flow learners when learning materials are significantly harder than learners' ability. Educational practice may be interesting in the possibility of inconsistency between flow experience and learning performance.

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