International Journal of Engineering Education Vol. 31, No. 2, pp. 553–566, 2015
Printed in Great Britain
0949-149X/91 $3.00+0.00

Effectiveness of E-learning 2.0 Tools and Services to Support Learner–Learner Virtual Interactions in a Global Engineering Class

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This paper introduces our best practices of integrating a variety of e-learning 2.0 tools and services to support the learner–learner virtual interactions in a global engineering class, which is jointly offered by five world leading engineering schools with a total of 108 course participants. A qualitative data analysis was conducted to analyze the text chat history collected from this global engineering class. The effectiveness of four specific e-learning tools/services are evaluated and compared. These include: discussion board on learning management system, web conferencing service, mobile messaging service, and social networking service. According to the analysis results, different tools/services play complementary roles in supporting diverse kinds of learner–learner virtual interactions, and some overlapping roles in between certain tools/services may inspire development of future e-learning tools/services.

Keywords: e-learning 2.0; learner–learner interactions; global class

1. Introduction

In general, various class interactions can be classified into three categories: learner–content, learner–teacher, and learner–learner [1–3]. Out of which, the importance of learner–learner interactions has been widely recognized [4–7]. Since the face-to-face interactions can never go beyond the physical boundaries of time and space, many efforts have been devoted to studying the virtual interactions in the context of distance education and its recent scale up to a Massive Open Online Course (MOOC) [8–11]. Early solutions of learner–learner virtual interactions include e-mail, computer conference, and bulletin board systems [12–13]. Recently, as e-learning keeps gaining its momentum, there emerged a number of studies focusing on the synchronous interactions in the e-learning environment [14–16]. In that regard, the unique values of e-learning 2.0 [17–19] hinge on its great potential to enable interactive learn–learner or peer–peer learning. E-learning 2.0 is significantly different from e-learning 1.0 in the sense that the latter features a linear delivery of content knowledge from a single teacher to multiple learners, whereas the former is characterized by the multi-perspective exchange of contextual understandings among learners by themselves.

So far, however, our understanding remains limited in specific to the effectiveness of different e-learning 2.0 tools and services to support many kinds of learner–learner virtual interactions. Furthermore, as today's engineering education becomes increasingly globalized [20–22], the virtual interactions are often coupled with cross-national and cross-cultural interactions [23], making investigation of the learner–learner virtual interactions even more complex. This study has three objectives. First, we intend to introduce our best practice of integrating a variety of different e-leaning 2.0 tools and services to support the learner–learner virtual interactions for a global engineering class that is jointly offered by five leading engineering schools with 108 participants. Next, we aim to evaluate and compare the effectiveness of these different tools/services, to explore their individual advantages and disadvantages, and to identify their complementary or duplicative roles in supporting different kinds of learner–learner interactions. Finally, based on the lessons learned, we will to propose or predict some possible evolvement towards future and better e-learning tools and services.

The rest of this paper is organized as follows. Section 2 presents the background of a global engineering education program, called iPodia, upon which the study is motivated and conducted. Section 3 introduces our best practices of integrating four specific e-learning tools/services to support the learner–learner interactions for a global engineering class. Section 4 explains our research methodology with respect to its participants, data collection, data analysis, and analysis result. Section 5 includes some discussions and lessons learned. Section 6 draws conclusions and outlines future research directions.

* Accepted 1 September 2014.

2. Background

This study is conducted upon a global engineering education program, called iPodia, which advocates the 'global', 'borderless', and 'interactive' learning. The iPodia program was initiated by the Viterbi School of Engineering at the University of Southern California in 2009. Its mission is to leverage modern pedagogical and technological innovations to enable students around the world (hence 'global') to engage in peer-to-peer interactive learning (hence 'interactive') across disciplinary, physical, institutional, and cultural boundaries (hence 'borderless').

The iPodia pedagogy is characterized by a seamless integration of 'inverted learning', 'interactive learning', and 'international learning' [24]. 'Interactive learning' lies in the center of the iPodia pedagogy, because it plays the role of linking the 'inverted learning' and 'international learning'. iPodia believes that context is the key to solving many of today's critical engineering problems, unlike content knowledge that can be lectured by teachers, contextual understanding is best constructed when learners engage in interactions with each other. In the traditional teaching/learning practice, the valuable class time is mostly occupied by the teacher to lecture content knowledge, while for a few times it was left for students to effectively interact with their peers. This is the reason why iPodia adopts the flip teaching method to completely invert the focus in the classroom. Furthermore, iPodia takes the stand that a student's learning opportunity will be greatly increased with their study with and from the peers who are very different from them. As a result, iPodia also highlights the importance of international learning. Unlike the traditional solutions of the study abroad program or student exchange program that are often expensive for students to afford, iPodia leverages videoconferencing technology and e-learning tools/services to enable students to interact with their global peers without leaving their home campuses.

An independent, nonprofitmaking, global education consortium from among the world's leading universities, namely the iPodia Alliance, has been established since 2012. Member universities of the iPodia Alliance collaborate strategically to build global classes to address important engineering subjects that have global impacts. As of spring 2014, the current members of the iPodia Alliance include:

1. University of Southern California (USC), Los Angeles, USA
2. Peking University (PKU), Beijing, China
3. National Taiwan University (NTU), Taipei, Taiwan
4. Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea
5. Technion—Israel Institute of Technology (TECHNION), Haifa, Israel
6. RWTH Aachen University (AACHEN), Aachen, Germany
7. India Institute of Technology—Bombay (IITB), Mumbai, India
8. Escola Politécnica da Universidade de São Paulo (EPUSP), São Paulo, Brazil
9. Birla Institute of Technology and Science (BITS), Pilani, India
10. Qatar University (QU), Doha, State of Qatar.

To date, a variety of different global engineering courses have been developed, offered between different member universities of the iPodia Alliance. So far, the engineering subjects being covered include 'Principles and Practices of Global Innovation', 'Management of Global Engineering Teams', 'Computer System Architecture', 'Sustainability in the Built Environment', 'VLSI System Design', etc.

An advanced iPodia technical platform has been developed based on the existing distance education facilities at each participating university in order to realize the above iPodia pedagogy and to deliver various global courses. Upon which, a variety of different e-learning technologies, tools, and services are integrated to support different kinds and levels of interactions. In particular, the video-conferencing technology is employed to connect multiple iPodia interactive classrooms located in different member universities of the iPodia Alliance. As a result, it has been made possible that the learners enter their local classrooms but learn together with global classmates synchronously. Figure 1 illustrates an existing iPodia interactive classroom located on the KAIST campus in South Korea.

A great challenge for this kind of global class is how to reinforce the sense of 'cohesiveness' among participants outside the classroom [25–28]. The joint lectures on a weekly basis are barely the minimum to make students bond with each other and to collaboratively work together on team projects. Therefore, we integrated a variety of e-learning 2.0 tools and services to promote and support the learner–learner virtual interactions, which include: discussion board on Learning Management System (i.e., Blackboard System), web conferencing service (i.e., Adobe Connect), mobile messaging service (i.e., KakaoTalk), and a social networking service (i.e., Facebook). The implementation of each tool/service will be specified in Section 3.

Fig. 1. An existing iPodia interactive classroom located on the KAIST campus.

3. E-learning 2.0 tools and services

3.1 Discussion board

A discussion board is an important tool contained in the learning management system (LMS) [29]. LMS is a web-based software application that functions to manage, store, track, and deliver different formats of lecture materials. In the past, the LMS has been widely used to facilitate distance education [30–31]. The existing 'Blackboard Platform' managed by the Distance Education Network (DEN) at USC is used to build the iPodia LMS. All course participants are provided with individual accesses to the iPodia LMS, and they rely on the discussion board function to interact with each other in an unsynchronized manner. Before class, all students are required to preview the lecture materials (e.g., video, slides, additional readings, etc.) posted on the LMS in advance and to provide their early feedback on the discussion board. During class, the teacher first gives a short reflection of the lecture materials based on analysis of the students' early feedback, then the teacher engages the students in different kinds of interactive learning activities, such as questions/answers, free discussions, team projects, etc. After class, students are required to participate in the discussion board again

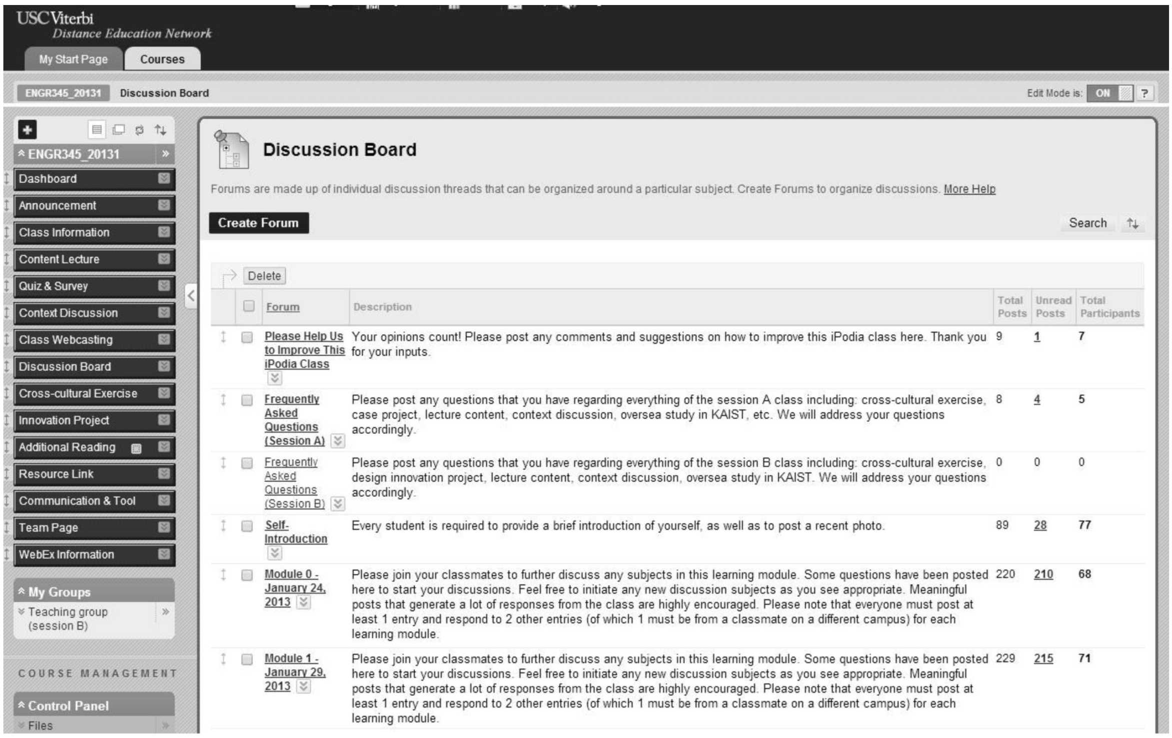

Fig. 2. Illustration of learner–learner interactions that occurred on the discussion board.

to continue and deepen the interactions initialized during class. Figure 2 illustrates the discussion board on the iPodia LMS.

3.2 Web conferencing service

The web conferencing service is an online service that enables the basic conferencing activities to be interactively carried out by remote users in different locations. In general, a typical web conferencing service includes functions such as desktop sharing, whiteboard file sharing, video streaming, audio communication, text chat, poll/surveys, meeting recording, etc. In industry, the web conferencing service is commonly used to support virtual meeting, training, presentation, etc., whereas, in university, its applications are mostly found in distance education [32–33]. For instance, the service is often used to enable remote students to watch live lecture broadcasting in front of their personal computers. That being said, in the past, the service was primarily used to enable the teacher–student interaction as opposed to learner–learner interactions. In iPodia, the web conferencing service functions to facilitate the synchronized learner–learner virtual interactions in the classroom. A public conference room is created and kept available through the entire course duration, and all course participants are provided with access to this conference room. During class, all students are strongly encouraged (almost required) to bring their laptops (or tablets) to the classroom, to login in the conference room, and to instantly share their feedbacks over the lecture content. By doing so, students are enabled to interact with each other while the teacher is simultaneously lecturing content. Furthermore, the web conferencing service is also found useful to support various virtual interactions occurring outside the classroom, such as project collaboration (i.e., teammate–teammate interactions), office hour (i.e., teacher–student interactions), and course grading (i.e., teacher–teacher interactions). Among a variety of competing web conference services (e.g., WebEx, Google Hangout, etc.) available on the market, our choice is ‘Adobe Connect’. Figure 3 illustrates the typical layout of an Adobe Connect conference room, with its major functions highlighted.

3.3 Social networking service

The social networking service enables its users to virtually develop, maintain, and expand his/her social relations with others based on shared interests, backgrounds, and connections. To date, many efforts have been devoted to studying the diverse impacts of the social networking service on a person’s learning process [34–35]. In particular, some attempts have been made to transform the social networking service to become an alternative of the learning management system [36–38], focusing on the unique role that the service plays in facilitating knowledge-sharing among group members [39]. The social networking service is used to support our iPodia course, because ‘expand global social network’ is an important motivation for students signing on a global engineering class [40–42]. Among a variety of different social networking

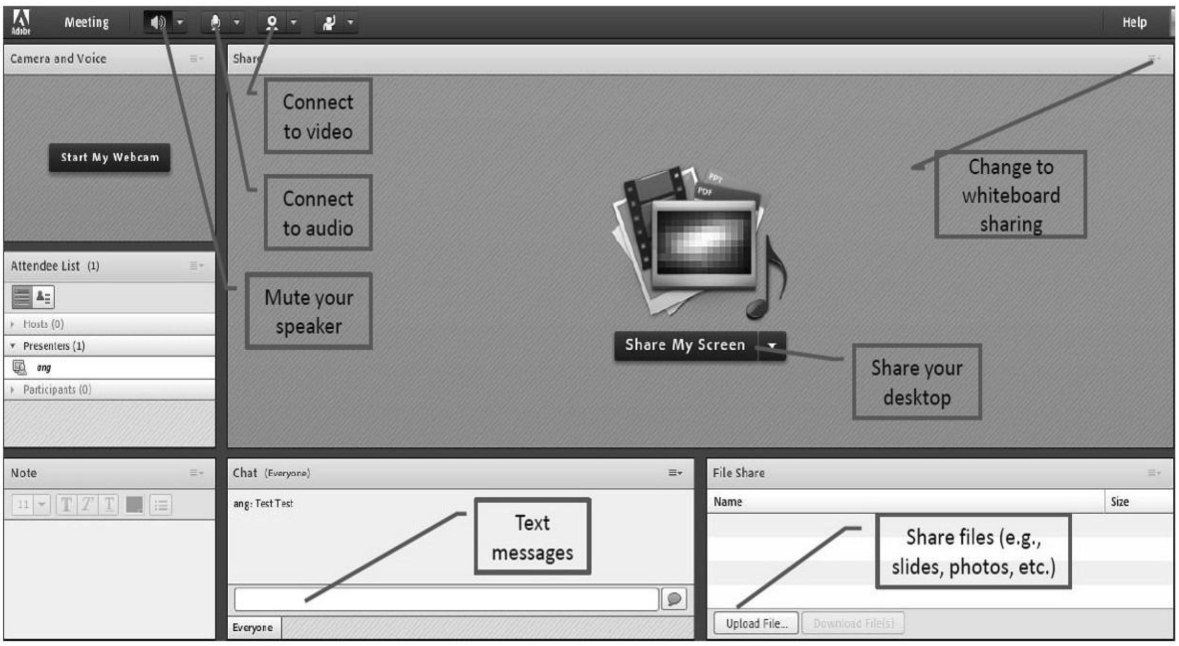

Fig. 3. Illustration of a typical Adobe Connect conference room.

Fig. 4. Illustration of learner–learner interactions that occurred on Facebook.

services available on the open market (e.g., Facebook, Google+, Twitter, etc.), Facebook was selected because it is the dominating service in the majority of the member universities of the iPodia Alliance. The only exception is PKU, where a student's access to Facebook is limited by the Internet Censorship policy in China. To overcome this limitation, every PKU course participant was further provided with an individual virtual private network (VPN) account to access Facebook. Figure 4 illustrates some learner–learner interactions that occurred on Facebook.

3.4 Mobile messaging service

The mobile messaging service refers to the free communication-by-message service operated on mobile devices. It is often characterized by the free functions of text messaging, hold-to-talk messaging, emotion symbol messaging, photo/video sharing, location sharing, etc. Recently, the potential of mobile learning is drawing increasing attention [43–45]. We were inspired to use the mobile messaging service to support our global class in the light of the observation that students often create group chats via the mobile messenger to share, discuss, and comment on their learning experiences. For every iPodia class, we will create a public class chat room on the mobile messaging service, and all course participants are encouraged to install the messenger on their mobile devices, to sign up the class chat room, and to engage themselves in the peer–peer mobile interactions. Unlike the social networking service, there lacks a dominating mobile messaging service that is widely used worldwide. Take our choice of KakaoTalk Messenger, for instance, the vast majority of its active users are located in Japan and South Korea. Figure 5 illustrates some peer–peer interactions that occurred on the mobile messaging service.

4. Research methodology

This section presents our research methodology. We begin with a short introduction of the iPodia course upon which the study was conducted. Next, we describe the process of how the raw data of learner–learner interactions were collected from different e-learning tools/services. Next, we explain the process of how a qualitative data analysis was conducted to identify, categorize, and code the occurrence of different kinds of learner–learner interactions that occurred on different tools/services. Finally, we present the analysis results and use statistical means to compare different tools/services. Such result will help us to answer the following questions in Section 5: Which e-learning tool/service is most effective in supporting what kind of interactions, and are there any redundancy or complements between different tools/services?

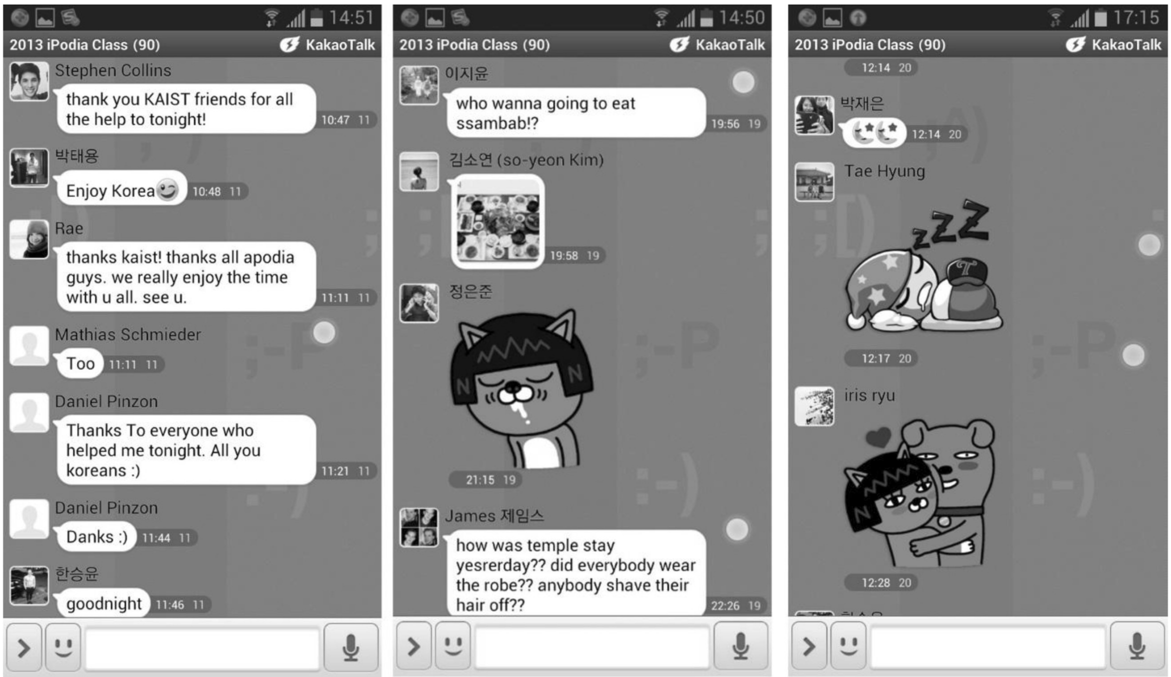

Fig. 5. Illustration of learner–learner interactions that occurred on KakaoTalk.

4.1 Background and participants

This study is conducted on a particular iPodia course, called 'Principles and Practices of Global Innovations', which has been consecutively offered for four years since 2010. In spring 2013, the course was jointly offered at five member universities of the iPodia Alliance: the University of Southern California (USC) in the USA, Peking University (PKU) in China, Korea Advanced Institute of Science and Technology (KAIST) in South Korea, Technion—Israel Institute of Technology (TECHNION) in Israel, and the RWTH Aachen University (AACHEN) in Germany. Participants of the course included a total of 108 college students (i.e., 36 USC, 18 PKU, 18 KASIT, 18 TECHNION, and 18 AACHEN students). In consideration of the time differences, the class was divided into two parallel sessions: session A and session B. Session A consisted of 18 USC-A, 18 TECHNION, and 18 AACHEN students, and Session B included 18 USC-B, 18 PKU, and 18 KAIST students. Because of the rigorous student selection process conducted upfront, the students can be regarded as being representatives of the best student population in each participating school. For example, two thirds of the USC class were Trustee or Presidential scholars. Table 1 summarizes the backgrounds of the course participants.

4.2 Data collection

The data we intended to collect include all kinds of learner–learner virtual interactions that occurred on different e-learning tools and services. In general, there are two requirements for a systemic data collection process: completeness and objectivity. In a way specific to this study, that is to say, all learner–learner virtual interactions must be comprehensively collected in an operator-independent manner. Fortunately, this is made possible by the default 'export chat/message history' function available in all the four tools/services. It should be noted that the data being collected merely represents a portion of all such interactions ever occurring in this iPodia class. For example, there were also abundant

Table 1. Summary of class participants' backgrounds

Session	University	Class size	Grade year	Engineering/Non-engineering majors	Male/Female
Session A	USC-A	18	Sophomore and Junior	12/6	10/8
TECHNION	18	Senior	18/0	15/3	
AACHEN	18	Master	18/0	15/3	
Session B					
	USC-B	18	Sophomore and Junior	14/4	9/9
PKU	18	Juniors	6/12	10/8	
KAIST	18	Juniors and Seniors	18/0	11/7	

interactions that occurred on emails, Skype meetings, phone calls, etc. In addition, because certain student teams had hesitated to make their internal team chat histories public, in particular to the teacher, we only collected and analyzed the complete peer–peer virtual interactions that occurred at the class level instead of at the team level. For instance, it was common that every team had its private chat room on KakaoTalk, and every school had its exclusive alumni Facebook page.

4.3 Data analysis

A rigorous data analysis is conducted to investigate the chat histories collected from different tools/services. Since the interactions all appeared in the format of text messages, they are all qualitative data as opposed to quantitative data. Therefore, we must first transform these text-based qualitative data (i.e., the back and forth text messages) into the number-based quantitative data (i.e., the numerical count of different kinds of interactions), so that we can use certain statistical means to conduct assessments and comparisons in the next step. Qualitative data describes items with respect to a certain categorization, and they can be converted to quantitative data by means of counting. A complete qualitative data analysis process includes five steps [46]: data sourcing, transcription, unitization, categorization, and coding. Unlike verbal interactions that must be transcribed by a third-party, the text-based interactions that we collected have already been digitized by the users, therefore, the first two steps no longer apply. As a result, our qualitative data analysis includes three key steps: unitization, categorization, and coding.

The 'unitization' step divides the mixed raw data into a number of separate small coding units. The chat history is a combination of text messages posted by different users. Every text message can be regarded as an attempt to initiate an interaction. However, not all interaction attempts are necessarily successful, just as not every thread posted on a discussion board receives responses. Therefore, the first sub-step of 'unitization' is to exclude the messages that failed to attract any follow-up response (or reply). For the remaining messages, we associate relevant messages to form the basic coding unit of an interaction-pair. Every interaction-pair contains a combination of two interrelated messages posted by different users. The adjacent messages posted by the same user to address the same topic are combined. Within a certain interaction-pair, the first message and the second one each represents an interaction attempt and an interaction response, respectively. Furthermore, because different interaction-pairs are intended to address different topics, all relevant interaction-pairs are further grouped together to form another coding unit of interaction-topic. Since an interaction-topic mostly contains more than one interaction-pair, hence, the latter can also be regarded as a subset of the former. Moreover, the number of interaction-pairs contained in a certain interaction-topic can be regarded as an indicator of that interaction-topic's level of interest to the users.

At the end of the 'unitization' step, we arrived at a set of two types of coding units: interaction-pair and interaction-topic. An illustrative example is provided to show the above 'unitization' process. The chat history below contains 12 messages posted by 5 different individuals (i.e., Christine, Kes, Enjun, Sundong, and Quentin). A total of 11 interaction-pairs are identified by combing related messages: $1 \leftrightarrow 2$, $1 \leftrightarrow 3$, $3 \leftrightarrow 4$, $4 \leftrightarrow 5$, $5 \leftrightarrow 6$, $6 \leftrightarrow 7$, $6 \leftrightarrow 8$, $8 \leftrightarrow 9$, $9 \leftrightarrow 10$, $10 \leftrightarrow 11$, $11 \leftrightarrow 12$. Since all these interaction-pairs were determined to have addressed the same topic of '*mobile phone situation in Korea*', they are grouped together as a single interaction-topic.

1. 4:38 pm, May 11, 2013, Christine Xu: Hey KAIST students! In terms of a phone situation, what do you guys recommend? If I bring an unlocked phone, how much are data plans? Or is wi-fi sufficient?
2. 5:01 pm, May 11, 2013, Kes Rittenberg: I wana know too!
3. 5:05 pm, May 11, 2013, Eunjun: it says 100 mb prepaid 5$, 4 gb 40$. but I'm not sure this service is open to visiting foreigners.
4. 5:08 pm, May 11, 2013, Kes Rittenberg: Can you get it for us and then give us the sim Card? And we pay you back?
5. 5:11 pm, May 11, 2013, Eunjun: oh it says also open to foreigners, but i don't really know how to buy prepaid card or usim cos prepaid is not so common in Korea.
6. 5:12 pm, May 11, 2013, Kes Rittenberg: Oh are micro SIM cards common?
7. 5:15 pm, May 11, 2013, Eunjun: for iphone? nope i think most prepaid sim is normal usim. try this ssppmm.tistory.com/2843, or maybe seller has one like this.
8. 7:34 pm, May 11, 2013, Sundong Kim: We will bring you to KAIST phone store. they sell USIM but please unlock your phone before your departure.
9. 8:17 pm, May 11, 2013, Quentin: Illegal to unlock phone now :(
10. 8:22 pm, May 11, 2013, Sundong Kim: Then when and where can you do? you cant do it in Korea.
11. 8:57 pm, May 11, 2013, Quentin: Technically you can unlock with computer but don't know how they'll track that.

12. 9:05 pm, May 11, 2013, Sundong Kim: I meant you have to bring you phone to telecom company branch (tmobile verizon. etc) and unlock it, if you want to use it in Korea!

The next step of 'categorization' is critical to any qualitative data analysis, because it establishes the scheme of categories situated to the unique research problem. In general, various learner–learner interactions can be classified into three categories: academic, collaborative, and social [3]. The three types of learner–learner interactions differ from each other largely with respect to the interaction topic being addressed. First, the academic interactions occur when the learners exchange different interpretations over the same piece of lecture content (e.g., concept, principles, methods, models, examples, etc.) that they learned in the classroom. In other words, the academic learner–learner interactions are centered on the topic of 'lecture content'. Next, the collaborative interactions occur when the learners engage in collaborations (or seek for collaborations) in order to jointly finish certain course tasks, for instance a team project, which explicitly requires teamwork rather than individual work to accomplish. As a result, the collaborative learner–learner interactions can be regarded as addressing the topic of 'course tasks'. Finally, social interactions occur when the learners intend to receive social feedback from others through 'personal encouragements and motivational assistance' [3]. As a result, the topic of social interactions is often situated in a variety of social issues, which are related to a person's personal life outside the classroom and are independent of the lecture content and course task. Based on the above discussion, in this study, various interaction-topics are classified into three kinds: 'lecture content', 'course task', and 'social issue'.

Furthermore, depending on whether an interaction is stimulated because of cultural reasons (e.g., the lack of knowledge of another's culture) or if the interaction itself contains cross-cultural content, various learner–learner interactions can be further divided into two kinds: non-cultural interactions and cross-cultural interactions. The combined consideration of the two classification methods leads to a more precise classification of interaction-pairs: non-cultural academic (NA), cross-cultural academic (CA), non-cultural social (NS), cross-cultural social (CS), and collaborative interaction (CI). Note that, because it is difficult in practice, if not impossible, to objectively determine whether a collaborative interaction contains any cross-cultural efforts, the collaborative interaction was not further divided according to the cross-cultural and non-cultural distinction. Table 2 summarizes some illustrative examples for each type of interaction-pair.

The final step is 'coding', which assigns a category code to every coding unit. All the interaction-topics are first coded, followed by coding of the interaction-pairs contained within each interaction topic. In general, the interaction-pairs contained within the interaction-topic of 'lecture content', 'course task', and 'social issue' should be each classified as 'academic', 'collaborative', and 'social' interactions, respectively. Next, the 'academic' and 'social' interaction-pairs are further examined with respect to the non-cultural and cross-cultural distinctions.

The above qualitative data analysis process is summarized as follows:

Step 1 Unitize the chat history into separate coding units.

1.1 Identify the messages that failed to receive any response.

1.2 Combine adjacent messages posted by the same user addressing the same topic.

Table 2. Illustrative examples of different types of interaction-pairs

Interaction pair	**Illustrative examples**
Non-cultural Academic (NA)	• PKU student: 'according to the ppt slides, the influencing factor on the beginning and the end of a technology on the market are different. What are some of the reasons leading to that?' • 'KAIST student: 'If you look into the slides, you can see three different stages of an S-curve. In the beginning you see the Innovation Stage where performance is the only factor that matters. An example would be the performance of mp3 players or the touch-sensor of an iPad.'
Cross-cultural Academic (CA)	• KAIST student: 'There was a discussion in class about cultural invention like a kimchi refrigerator. Let me introduce Korean food garbage drying machine, I heard that most of American people do not separate food garbage when throw away something . . .' • USC student: 'Cool! This is a great example! And you're totally right, that is definitely a korea-specific item, the US market's reason for separating food trash is completely different . . .'
Non-cultural Social (NS)	• USC student: 'happy birthday Tyler!!!(cake)' • KAIST student : 'I think maybe Tyler is still recovering . . . from the hearty birthday dinner and early night of rest (wink)'
Cross-cultural Social (CS)	• USC student: 'finally, home to a reasonably priced watermelon!' • KAIST student: 'please stop torturing me about the fruit prices . . . had a $20 watermelon last weekend . . . every bite was so precious'
Collaborative Interaction (CI)	• USC student: 'Are you free tomorrow or Friday?' • PKU student: 'Sorry, tomorrow I should be on the train back to school. I will arrive the day after tomorrow~'

Table 3. Quantity of messages, interaction-pairs, and interaction-topics on each E-learning tool/service

E-learning tools/services	Quantity of total post/messages	Quantity of total interaction-topics	Quantity of total interaction-pairs
Discussion board	1973	242	893
Adobe Connect	4587	406	3445
KakaoTalk	2652	346	1813
Facebook	678	76	464

Table 4. Count of different interaction-topics on each tool/service

E-learning tools/services	Lecture content	Social issue	Course task	Total
Discussion board	182	52	8	242
Adobe Connect	207	91	108	406
KakaoTalk	10	195	141	346
Facebook	5	39	32	76

Table 5. Count of different interaction-pairs on each tool/service

E-learning tools/services	Non-cultural academic	Cross-cultural academic	Non-cultural social	Cross-cultural social	Collaborative
Discussion board	226	500	23	118	26
Adobe Connect	1067	431	406	782	759
KakaoTalk	13	30	223	905	642
Facebook	10	12	38	272	132

1.3 Associate two interrelated messages to form the coding unit of interaction-pairs.
1.4 Group relevant interaction-pairs to form the coding unit of interaction-topics.

Step 2: Develop a scheme of categories of learner–learner interactions.

2.1 Categories of interaction-topics: lecture content (LC), course task (CT), and social issue (SI)
2.2 Categories of interaction-pairs: non-cultural academic (NA), cross-cultural academic (CA), non-cultural social (NS), cross-cultural social (CS), and collaborative interaction (CI).

Step 3: Code every interaction-topic and each interaction-pair.

3.1 Code every interaction-topic to be (LC), (CT), or (SI) as categorized in step 2.1.
3.2 Count the number of emergence of every type of interaction-topic.
3.3 Code every interaction-pair contained within each interaction-topic to be (NA), (CA), (NS), (CS) or (CI) as categorized in step 2.2.
3.4 Count the number of emergences of every type of interaction-pair.

4.4 Results

The above data analysis process was strictly followed to investigate the chat history collected from different e-learning tools/services (i.e., Blackboard Discussion Board, Adobe Connect, Facebook, and Kakaotalk) separately. Table 3 summarizes the result of performing the 'unitization' step in terms of the quantity of total messages, interaction-topics, and interaction-pairs. Tables 4 and 5 summarize the results of performing the 'coding' step with respect to the count of different kinds of interaction-topics (i.e., 'lecture content', 'course tasks', and 'social issues'), and the count of different types of interaction-pairs (i.e., 'non-cultural academic', 'cross-cultural academic', 'non-cultural social', 'cross-cultural social', and 'collaborative' interaction), respectively.

A one-way analysis of variance (ANOVA) was conducted to compare different tools/services with respect to the average number of interaction-pairs contained in (or concerning with) an individual interaction-topic, which is an indicator of the learner's interest to engage in interactions. The independent variables are the four e-learning tools/services, whereas the dependent variables are the number of interaction-pairs within the three kinds of interaction-topics (i.e., 'lecture content', 'social issue', and 'course task'). The findings are presented as follows, and summarized in Table 6.

Table 6. Mean count of interaction-pairs within each interaction-topic on different tools/services.

E-learning tools/services	Lecture content	Social issue	Course task
Discussion board	3.99	2.71	3.25
Adobe Connect	7.24	13.05	7.03
KakaoTalk	4.30	5.78	4.55
Facebook	4.40	7.95	4.13

- The average number of interaction-pairs within each interaction-topic of 'lecture content': Adobe Connect (i.e., mean = 7.24) significantly outperformed the Blackboard Discussion Board (i.e., mean = 3.99), KakaoTalk (i.e., mean = 4.30), and Facebook (i.e., mean = 4.40) (F = 74.22, F critical = 2.63, P-value = 0.00).
- The average number of interaction-pairs within each interaction-topic of 'social issue': the measure is significantly high on Adobe Connect and significantly low on Discussion Board, while KakaoTalk and Facebook fall in between.
- The average number of interaction-pairs within each interaction-topic of 'course task': Adobe Connect (mean = 7.03) significantly outperformed Discussion Board (mean = 3.25), KakaoTalk (mean = 4.55), and Facebook (mean = 4.13) (F = 74.22, F critical = 2.63, P-value = 0.00).

Because the above comparison concerns multiple dependent variables, a multivariate analysis of variance (MANOVA) was further performed in order to validate the significances identified based on the individual ANOVAs. The result shows that Adobe Connect significantly outperformed the other three tools/services, when the three dependent variables are considered as a signal vector.

Furthermore, we calculated the percentage of different kinds of interactions that occurred on every tool/service, by means of dividing the count of a certain type of interaction-pair (i.e., columns 2–6 in Table 5) by the quantity of total interaction-pairs (i.e., columns 2–4 in Table 3). The results are illustrated in Fig. 6. This measure makes visible the dominating interaction type on each tool/service.

Last but not least, for each type of interaction-pair, we calculated the contributions of different tools/services: divided the individual count on a certain tool/service (i.e., rows 2–5 in Table 5) by the total counts on all four tools/services (i.e., a total of 6615 interaction-pairs). This measure makes visible the most useful tool/service in supporting a certain type of learner–learner interaction (Fig. 7).

Last but not least, we also obtained some concrete student feedback, which is directly related to the use experiences of the e-learning tools/services. This feedback comes from two sources: an open class reflection and a confidential course evaluation. The class reflection session was organized right before the class ends in order to solicit the participant's open suggestions for future course refinement. The course evaluation (i.e., a confidential online survey) included two parts: the first part contained a set of multi-choice questions, aiming at soliciting the participant's overall satisfaction with the course; the second part contained 20 open-ended questions, aiming to solicit the participant's personalized learning experience. It should be noted that the use experience of e-learning tools/services is among a variety of different course aspects that were reflected, and not every participant contributed to the two sessions equally. As a result, such feedback is presented in its 'original shape' in

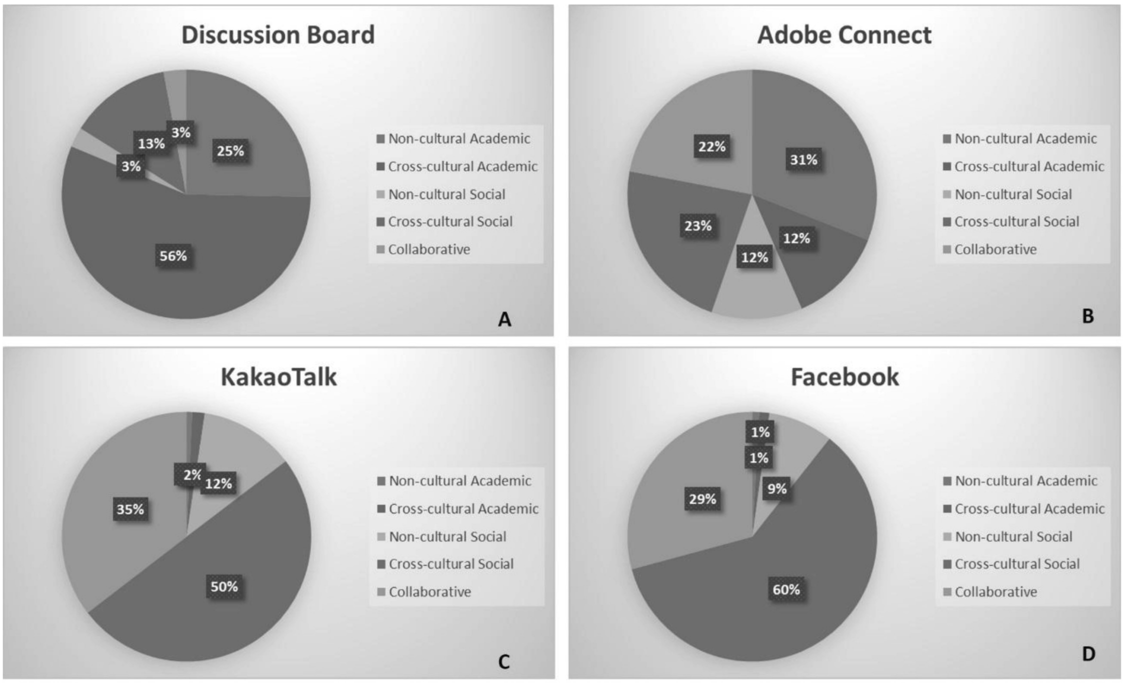

Fig. 6. Composition of different interactions on each e-learning tool/service.

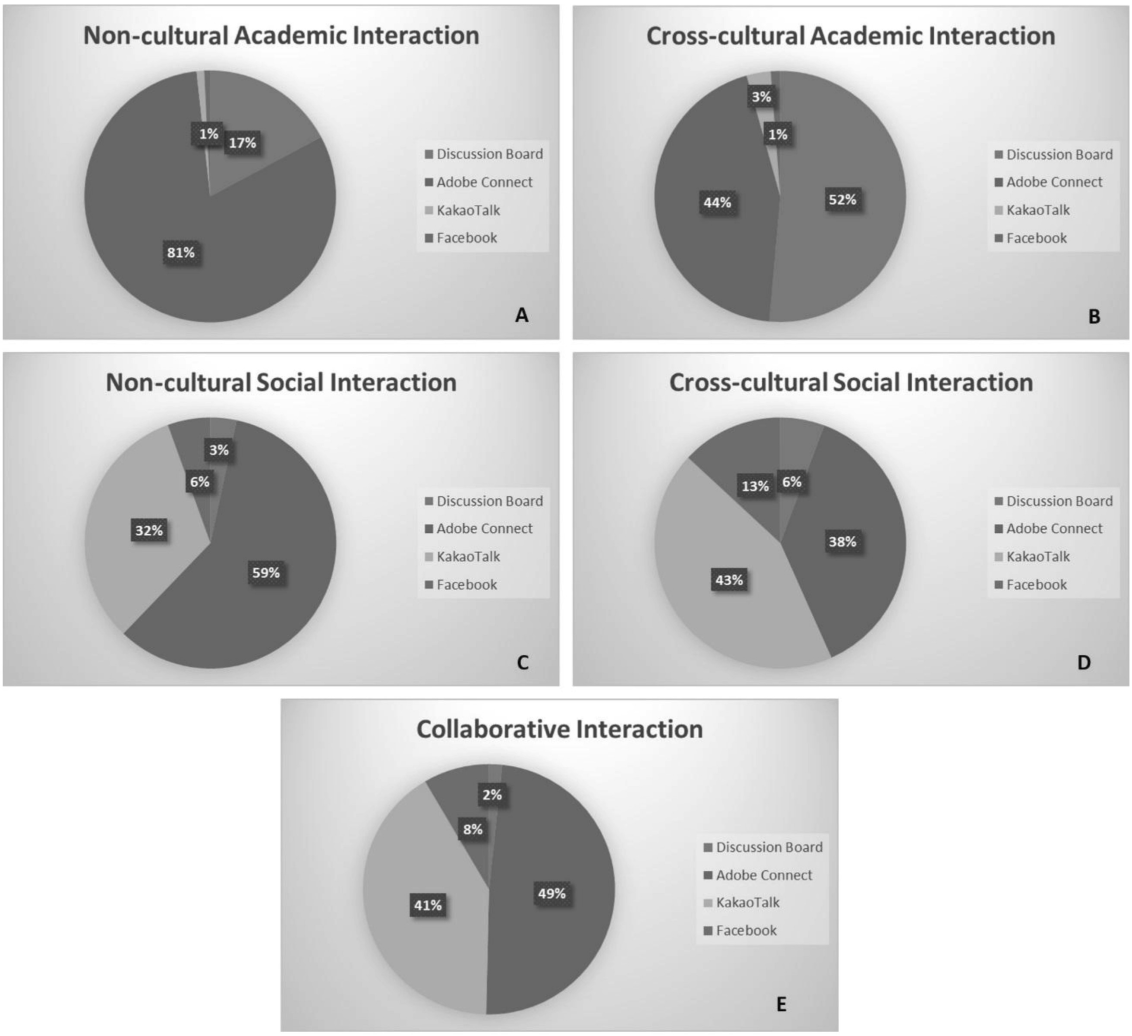

Fig. 7. Contributions of different tools/services for each type of interaction.

Section 5 as empirical evidence to support some of our conclusions.

5. Discussions and lessons learnt

The chat history on the Blackboard Discussion Board was dominated by the academic interactions in general and the cross-cultural ones in particular (see Fig. 6(A)). Moreover, it contributed the largest portion of cross-cultural academic interactions (see Fig. 7(B)). On the other hand, compared with other tools/services, the Blackboard Discussion Board barely contributed to the social interactions (see Figs 7(C) and 7(D)) and collaborative interactions (see Fig. 7(E)). It should be noted that though that the participation in the Blackboard Discussion Board had been listed as a mandatory class requirement, which counted as 10% of a participant's final grade. As a result, the relative importance of the discussion board might be overstated, and the result could be very different if such a requirement was removed. In fact, a number of course participants had strongly suggested excluding the Blackboard Discussion Board from future courses, because '*Blackboard is a bad way to discuss'; 'the discussion board was unorganized and did not facilitate productive discussions'; 'Blackboard was people inputting their own comments without any continuity to other people's inputs*'; '*The Blackboard discussion boards were pointless, but only because the medium made it so hard to respond and keep track of conversations*'; '*Blackboard is a clumsy and useless format for meaningful discussion*'. Furthermore, some participants had suggested different alternatives of the Blackboard Discussion Board, for example, '*look into Piazza or other forums*'; '*switch to a different site for the discussion board. Piazza, or even Facebook*'. Piazza is a representing example of many recently emerging web-2.0 based forum and wiki services, which has some advantages that may be leveraged to facilitate the learner–learner virtual interactions. First, Piazza supports both synchronous and asynchronous interactions. Second, it can be accessed by mobile devices, leading to the possibility of combining the web forum service with the mobile messaging service in the future. Next, Piazza's layout is designed to be a mixture of wiki and forum style. For example, for every question, it only allows a single answer to be 'community-edited' by all users. As a result, the user no longer needs to go through all threads to search and compare different answers. Last but not least, Piazza is also compatible with many existing LMS. In our 2014 spring class, Piazza was used as a replacement for the Blackboard Discussion Board, and a follow-up comparison of the two forum services is currently in progress.

On top of the highest quantity of total message, interaction-topics, and interaction-pairs, Adobe Connect significantly outperformed other tools/services with respect to the average number of interaction-pairs within an individual interaction-topic, which is an indicator of the interaction's depth. This is to suggest that the learner–learner interactions on the web conferencing service attracted more students to participate, and the interactions are composed of more back-and-force rounds. On the one hand, it is expectable that Adobe Connect contributed the largest portion of non-cultural academic interactions (see Fig. 7(A)), because the service was intended to enable the learner–learner virtual interactions in the classroom (see Section 3.2). On the other hand, to our great surprise, the service also contributed the largest portion of social interactions (e.g., greet each other, discuss latest news, etc.) and collaborative interactions (e.g., clarify course task, look for teammates, coordinate project meetings, etc.). In addition, unlike other tools/services that are all dominated by one particular kind of interaction, Adobe Connect features a more balanced composition of different kinds of interactions (see Fig. 6(B)). Some student feedback also supported the above findings, for instance, '*the Adobe Connect helped with speaking to my classmates abroad*', '*some technologies such as Adobe Connect are well-suited for the type of interactions this course needs*', etc. It should be noted , though, that allowing students to engage in the peer-to-peer virtual interactions in the classroom could be a double-edged sword. On the one hand, as today's college students become increasingly used to multitasking [47–49], it will certainly stimulate many learner–learner interactions that would never happen otherwise. On the other hand, we cannot easily ignore the possible negatives of doing so, for instance, distracting students from a teacher's lecture. Careful guidance upfront and rigorous evaluation afterwards are both helpful. However, most importantly, based on our experience, some explicit rules must be made specifically to when such interactions are allowed and in what ways. In our class, for example, every lecture is divided into two parts. During the first half, the teacher lectures some specific concepts and methods, and the students are only allowed to text messages to each other on the web conferencing service. During the second half, the teacher uses the problem-based pedagogy to guide the class to exercise the taught concepts and methods, and the students are encouraged to turn on the video/audio functions to collaborate with each other.

The chat history on KakaoTalk is dominated by social interactions (see Fig. 6(C)), and the service contributes the largest portion of social interactions (e.g., post funny photos, plan social activities, etc.), and the second largest portion of collaborative interactions (e.g., coordinate meeting time, update project progress, etc.). It should be no surprise that the interactions on KakaoTalk are largely socially-oriented (see Fig. 7(D)), after all, even the mobile messaging service itself is rapidly evolving towards a social networking tool. However it is inspiring to find that KakaoTalk also plays an important role in supporting the collaborative interactions (see Fig. 7(E)). In a global engineering class, because its participants are all located in different time zones following different academic calendars and time practices (e.g., the Daylight Saving), the effective coordination of virtual meeting schedule/agenda often becomes a great challenge. For example, more than half of the class attributed '*team meeting coordination*' as one of the greatest challenges that they encountered during the learning process. In that regard, the traditional solution of e-mail is far from ideal because it is born to be an asynchronous tool, while the mobile messaging service demonstrates some exclusive advantages due to its 'mobile' nature. For example, many participants attributed their preference for KakaoTalk to its features of '*instant response*' and '*concise content*', and '*emotional signals*'. In the future, one possible improvement is to combine the mobile messaging service with the social networking service, as the two services share very similar compositions of different interactions (see Fig. 6(C) and 6(D)) and play highly identical roles in supporting different interactions (see Fig. 7).

It should be no surprise that the chat history on Facebook is dominated by social interactions in general and the cross-cultural ones in particular; what goes beyond expectations is that it also composes a reasonably high level of collaborative interactions (see Fig. 6(D)). In comparison with other tools/services, the contribution of Facebook to the overall learner–learner interactions can almost be ignored, except for the cross-cultural social interactions (see Fig. 7(D)). However, it remains necessary to continue providing the social networking service to a global engineering class, because '*expanding my global social network*' was one of the most frequently mentioned reasons why students signed up this iPodia class. Other motivations include: '*to meet/interact with foreign students*', '*to deepen understandings of other cultures*', and '*to build new skills of cross cultural and national collaborations*', etc. In the future, one possible change is to replace or to complement Facebook with Linkedin or Twitter. In practice, it is not unusual that a college student often uses all three services at the same time. In the past, the comparison of Facebook, Linkedin, and Twitter was mostly approached from the business perspective, few efforts have been devoted to examining their applications in the context of global engineering education.

6. Conclusion and future works

This study aims to investigate the effectiveness of a variety of e-learning 2.0 tools/services in supporting different kinds of learner–learner virtual interactions. A qualitative data analysis was conducted to analyze the chat history on different tools/services, which were all collected from a global engineering class that was jointly offered by five world leading engineering schools with 108 students. Four kinds of e-learning tools/services were examined and compared. These include: discussion board, web conferencing service, mobile messaging service, and social networking service. The analysis indicated some interesting findings. The chat history on the discussion board is dominated by academic interactions in general and cross-cultural ones in particular, while the tool failed to support collaborative and social interactions well. In addition, the discussion board was badly criticized by many course participants largely due to its 'unsynchronized' nature. The web conferencing service is characterized by a relatively balanced support of all kinds of interactions, and it contributed the largest portion of academic and collaborative interactions. In particular, it significantly outperformed other tools/services with respect to the average number of interaction-pairs within an individual interaction-topic. The chat history on the mobile messaging service and social networking service are both dominated by social interactions. Moreover, the mobile messaging service is also found useful in facilitating collaborative interactions. Based on the best practices, we conclude that different e-learning tools/services can indeed be effectively integrated together to support the learner–learner virtual interactions for a global engineering class. According to the empirical analysis, we further conclude that these tools/services play complementary roles in supporting different kinds of learner–learner virtual interactions, and some overlapping roles in between certain tools/services may be leveraged to develop new e-learning 2.0 tools/services.

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