Unbundling teaching and learning in a flipped thermal physics classroom in higher education powered by emerging innovative technology

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The emergence of open online courses and flipped classrooms has brought new opportunities to unbundle the traditional university. This study aimed to investigate a thermal physics classroom integrated with an open online learning mode to afford various learning strategies for students in Taiwan. Moreover, we examined students' preferred learning modes by adopting a quasi-experimental design with questionnaires, pre-test and post-test scores, self-reported journals and interviews. A total of 89 students participated in the study. The instructor allowed all students enrolled in the class to choose their own preferred learning modes. All students had full access to all course materials in both open online course and traditional face-to-face learning contexts throughout the whole semester. We examined the learners' academic performance in each learning mode and surveyed their perceptions of the course. The findings of this study indicate that information technology can transform teaching and learning in a thermal physics classroom and challenge the instructor to tailor the course to meet students' diverse needs. Significantly, students adopted five learning modes, consisting of face-to-face, web facilitated, alternative blended, online learning and flipped learning. This study provides a valuable reference on how traditional on-campus higher education institutions could be unbundled to create student-centred learning approaches.

Implications for practice or policy:

- Educators could design a flexible delivery model, allowing students to choose five learning modes, consisting of face-to-face, web facilitated, alternative blended, online learning and flipped learning in terms of their learning style and time management.
- For students with sufficient background knowledge, the flipped learning mode provides the best learning performance.
- This study could provide administrators, educators and instructors with insights and new approaches in science, technology, engineering and mathematics education and improvements in their course policies.

Keywords: flipped classroom, distance learning, learning behaviour, improving classroom teaching, personalised learning

Introduction

Thermal physics includes core heat-related subjects such as thermodynamics, statistical mechanics, and kinetic theory. It is a required advanced subject for a wide range of undergraduate courses, including students studying physics, medicine, engineering and applied sciences (Georgiou & Sharma, 2010). Thermal physics covers the most fundamental physical processes, which could lead to a fuller understanding of science in general (Lewis & Linn, 1994; Linn & Songer, 1993). Leinonen et al.'s (2009) study concentrated on analysing university students' learning of thermal physics; the findings revealed that university teachers need to take great care in designing their teaching. Therefore, researchers have suggested that conventional lecture courses should be transformed to offer a student-centred, active learning approach to improve student learning in science (C. M. Chen & Wu, 2015; X. Chen & Wu, 2018; Mervis, 2013).

Fortunately, in recent years, the emergence of open online courses has provided a blend of learning approaches for higher education along with new opportunities and challenges. The information technology (IT) revolution has led to a rapid expansion and is now considered an essential requirement for universities to improve teaching and learning environments (Al-Qahtani & Higgins, 2013; Chan et al., 2019; Liu & Young, 2017). The knowledge-based economy has shown a broad and growing demand for innovative ways to provide education, which has led to remarkable changes in learning technology (Liu & Young, 2017; Shu & Gu, 2018; Weinhardt & Sitzmann, 2019; Wong et al., 2019; Zhang et al., 2004). The rapid growth of blended learning models in higher education is a recognition of the advantages of integrating technologies with conventional face-to-face teaching methods to allow students to access learning materials at their own pace as well as meet student demand for flexibility (Davidson, 2011; McKenzie et al., 2013; Twigg, 2003; Weinhardt & Sitzmann, 2019).

Net Generation students bring a variety of learning behaviours and attitudes when entering university, which also brings opportunities and challenges to higher education. However, there is still a gap between the IT environment in most academic institutions and the technology Net Generation students use. The biggest challenge for higher education leaders and faculty is understanding this generation of learners and providing suitable learning environments and services that can help them (Hartman et al., 2005; Weinhardt & Sitzmann, 2019). Although students can quickly find open online courses and learning resources that are both convenient and accessible, in the past, there were fewer empirical studies that focused on allowing learners to freely choose learning models that incorporated open courseware in formal courses. Therefore, this research is a valuable reference for higher education leaders and faculty to understand the new generation's learning behaviour.

Moreover, a growing number of higher education institutions have been involved in producing open educational resources and massive open online courses in higher education that might help create a new market and eventually disrupt the existing market (Weinhardt & Sitzmann, 2019; Wong et al., 2019). The theory of disruption can provide researchers, practitioners, and policymakers with a new perspective to increase affordable and accessible educational opportunities in our society (Christensen et al., 2001). Does this disruptive innovative technology have the potential to transform higher education? To address this issue, this study aimed to investigate how open online courses can be used to help institutions develop innovative approaches for teaching and learning and explored new learning modes to identify useful learning strategies. Moreover, we explored the emergence of open online courses to understand how and where they might be successfully deployed via disruptive innovative technologies.

Therefore, the following research questions guided this study:

- What learning modes would students prefer to adopt in a blended environment and what factors affect their preferred learning modes?
- What would be the learning outcomes in terms of academic performance based on their chosen learning modes?
- How did the students and teachers perceive the innovative teaching and learning in the learning contexts that integrate emerging technologies?

Literature review

E-learning in higher education

The emergence of the World Wide Web in the 1990s created new pedagogical opportunities for learning in higher education. Web technologies are widely used to create an online or partially online learning environment and supplement the various educational programs or training course. Web technologies can be used to supplement learning content, thereby changing the traditional face-to-face course. Learning management systems are ubiquitous and provide students with a web-based asynchronous learning environment, and students can engage in learning from any convenient place in their own time (Mason & Rennie, 2006; Reedy, 2019; Singh, 2003; Young & Hung, 2014). Urdan and Weggen (2000, p. 8) focused on content delivery and defined e-learning as “the delivery of content via all electronic media, including the Internet, intranets, extranets, satellite broadcast, audio/video tape, interactive TV, and CD-ROM”.

A number of studies have investigated the effect of e-learning and compared blended learning with traditional face-to-face in higher education (e.g., Akkoyunlu & Soylu, 2006; Alshwiah, 2009; Barnard et al., 2009; Bryner et al., 2008; Ernst & Colthorpe, 2007; Gurpinar et al., 2009; McFarlin, 2008; Taradi et al., 2005; Young & Hung, 2014). Moreover, Al-Qahtani and Higgins (2013) have compared the three methods – e-learning, blended learning and face-to-face classroom learning – in terms of their impact on students' achievement in higher education. Al-Qahtani and Higgins (2013) further clarified to what extent e-learning and blended learning approaches might promote students' achievement compared with face-to-face learning under similar circumstances. Therefore, this study aimed to conduct an experimental design to explore learning modes when students can access all course materials in both open online course and traditional face-to-face learning contexts throughout the whole semester and further discuss if there is a statistically significant difference among the various modes.

Blended learning and flipped classrooms

The University of Central Florida has described blended learning as "a pedagogical approach that combines the effectiveness and socialisation opportunities of the classroom with the technologically enhanced active learning possibilities of the online environment, rather than a ratio of delivery modalities" (Dziuban et al., 2004, p. 3). The flipped classroom is an innovative teaching concept that replaces the conventional classroom teaching method, allowing students to review, discuss and do homework with teachers in the class (Arnold-Garza, 2014). The flipped classroom means moving lectures out of the classroom and transferring actual homework to the classroom (Educause, 2012). There are many ways to flip the classroom. The basic premise is that students need to review the materials outside class and then participate in the learning activities guided by the instructor. The flipped classroom has many advantages: students can learn at their own pace; doing homework in class allows teachers to understand better the students' learning situation and the difficulties they encounter; students can also use class time more effectively; students' achievement, interest and participation levels improve (Fulton, 2012).

Flipped classroom design has been increasingly used in the wide range of university courses such as chemistry and physics (Arnaud, 2013; Sun & Wu, 2016). Studies on the use of video podcasts in science, technology, engineering and mathematics flipped classrooms support these findings. He et al. (2012) examined the use of video tutorials as a supplementary resource for undergraduate analytical chemistry courses. By discussing students' homework and exams in class, the instructor was able to identify concepts and problems that were particularly difficult for students. The findings showed that video podcasting is a flexible and cost-effective tool to improve students' mastery of chemistry problem-solving. Sun and Wu (2016) studied the effectiveness of the flipped classroom model and distance learning in physics courses. The results showed that learners who use flipped classrooms perform better in academic performance. They recommended that teachers provide learners with a combination of open courses and flipped classrooms.

Moreover, Medina (2018) studied the evolution of blended learning, including its use as a teaching strategy and delivery channel as well as the educational opportunities and challenges it presents. The results showed that effective blended learning must become more personalised, flexible and on-demand while cultivating learners' lifelong learning skills and practical use of technology. However, allowing students in the same class to attend classes according to their individual preferences has not been thoroughly discussed in the relevant literature. Therefore, this study examining the learning effect of flipped thermal physics classroom is important.

Methodology

Participants and setting

This study was conducted in the thermal physics course at a national university in northern Taiwan. The course was designed for students majoring in physics to learn advanced physics concepts, including classical thermodynamics, statistical mechanics and related theories. Ninety-nine college students enrolled in the course. However, after the one-semester-long survey, some of them did not finish the evaluation procedure. The final valid sample size was thus 89. All participants signed an informed consent form prior to this study and were informed that they had the option to opt out of participating in the research. Both qualitative and quantitative approaches were adopted in this study. Empirical data were collected over 5

months from September 2017 to February 2018. The triangulation method was used to improve the reliability of the study. Students' perceptions and learning outcomes were the focus of the evaluation.

Thermal physics is a required and very demanding advanced course for physics majors. The instructor gave the students full access to all course materials for flexible learning. The course offered students a choice of their preferred learning modes through the National Tsing Hua University OpenCourseWare website (National Tsing Hua University, 2010). The course instructor, Professor Hsiu-Hau Lin, an outstanding professor and winner of the Awards for OpenCourseWare Excellence (Open Education Consortium, 2014), was open-minded about delivering the course by means of a compelling and interactive teaching style to offer flexible learning approaches to thermal physics. He also provided a recommended course schedule for students' reference, which indicated the learning materials and videos for each week, as well as releasing all of his insightful notes with neat handwriting and hand-drawn comics to improve the students' video-based learning. The 18-week course included 54 lecture videos (about 75 hours), consisting of 26 topics in thermal physics, including Multiplicity, Binary Model System, Sharpness of Multiplicity Function and Superfluidity in Helium. For detailed information, please visit the course website (Lin, 2011).

Data collection and analysis

This study examined the learners' preferences for different learning delivery modes as well as their performance in the class and their perceptions of the course, using questionnaires, pre-test and post-test scores, self-reported journals and interviews with the students and instructor. The questionnaires were given to the students to ascertain their background knowledge of general physics, general physics laboratory, theoretical mechanics, applied mathematics and electrodynamics. The pre-test score was calculated from the background knowledge scores. The post-test score was measured from the students' final grades in the course, including two mid-term exams and the final exam in the semester. Moreover, to understand how the students learned at a distance, the self-reported journals were collected to gauge how much time they put into the course preparations, as well as which aspects of the course they considered to be useful or challenging so that the instructor could address their needs accordingly. Furthermore, individual interviews were conducted in Mandarin to understand the participants' experiences and perceptions. Participants were chosen and interviewed at the end of the semester. Based on their responses to the questionnaires and their self-reported journals, we identified five learning modes. To understand each learning mode more in-depth, we chose two representative students who performed well at the top in each mode for individual interviews. Therefore, there were a total of 10 students involved in the interviews. Each interview was 10 to 20 minutes long depending on each interviewee's response. The interview results were transcribed and then coded by three researchers. We translated the interview scripts from Mandarin into English. Furthermore, to protect the interviewees' personal information, we used codes such as E1-1M.

Results

The results presented here are based on both the quantitative and qualitative data analysed to address the aforementioned research questions.

Five learning modes for students in a mixed and adaptive blended environment

To answer the first research question, this study analysed the journal of each student and explored their learning modes based on the frequency of using open online courses and classroom learning. The analysis was done by three researchers. The results of interrater reliability indicate that the coefficients between any two of the researchers were all above 90%, which is highly reliable. The results indicate that there are five learning modes with the integration of open online courses and classroom learning (Figure 1): face-to-face (F2F), web facilitated (WF), alternative blended (AB), online learning (OL) and flipped learning (FL). The week number in Figure 1 is an example for the five different learning modes. The description, student numbers and percentages of each mode are listed in Table 1.

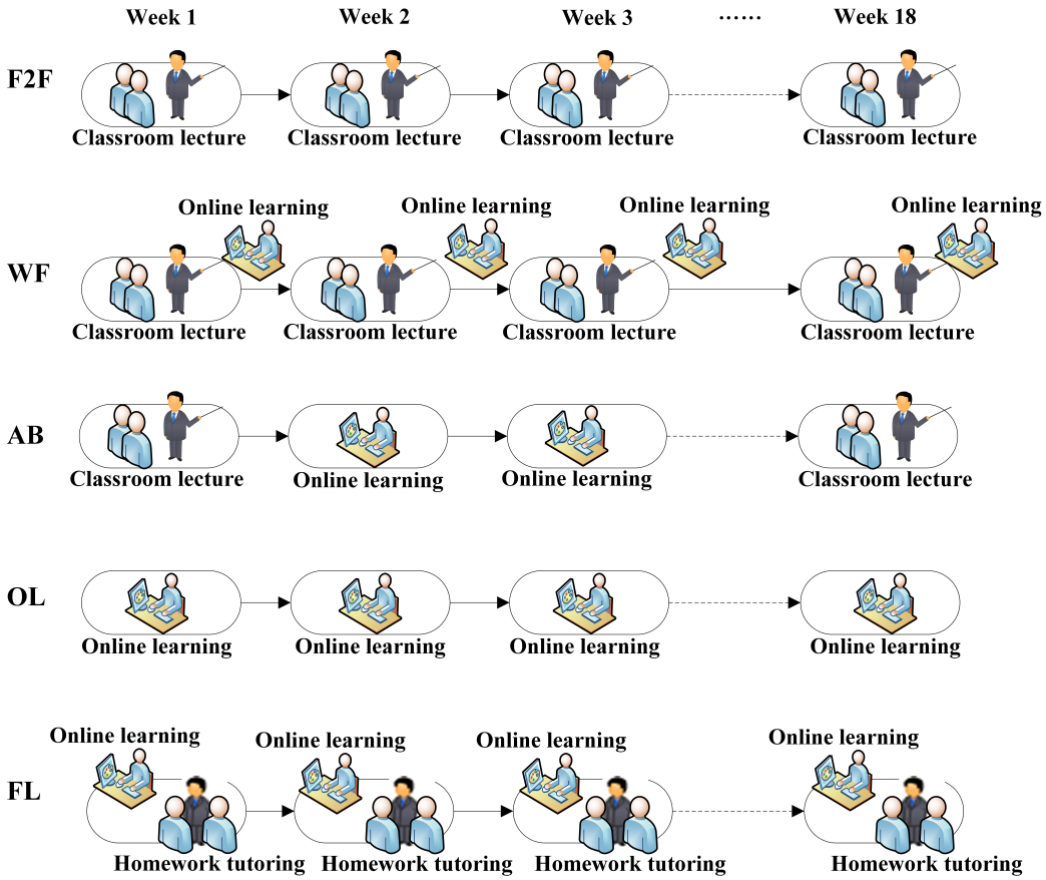

Figure 1. Five learning modes from the mixed and adaptive blended environment

Table 1
Learning modes (N = 89)

Learning methods	Description	Student numbers	Percentages
F2F	Learning in the classroom and meeting with the teacher on a regularly scheduled basis.	11	12.12%
WF	Learning in a face-to-face classroom with online materials.	30	33.33%
AB	Learning via blended online and face-to-face delivery. A substantial proportion of content is delivered online.	31	34.36%
OL	Learning courses via web-based instruction with streaming video delivering content.	6	5.05%
FL	Learning content via online video lectures and attending a face-to-face classroom to interact with the teacher to offer more personalised guidance and to answer homework or assignment problems.	11	13.13%
Total		89	100%

Learning outcomes in different learning modes

To judge the students' learning performance, we collected their pre-test and post-test scores. The pre-test scores were used to measure students' background knowledge of general physics, general physics laboratory, theoretical mechanics, applied mathematics and electrodynamics. The Shapiro-Wilk test was conducted to examine the normality of the data. None of the Shapiro-Wilk test results was significant, suggesting that the data were normally distributed ($p > 0.05$). As indicated in the independent sample t test, no significant difference was observed in the participants' scores between the groups on the pre-test (t =

0.821, $p = 0.986 > .05$), which indicates that five groups had decent learning levels prior to the study. To understand whether or not the learning modes impacted the students' academic performance, we examined the students' learning performance in each mode based on their post-test scores. One-way analyses of variance (ANOVA) were performed. Table 2 provides descriptive statistics of each group's scores and summarises the group comparison results. Significant differences in the mean scores were found among the groups ($F = 3.192$*, $p = .017 < .05$).

Table 2
Learning outcomes among different learning modes (N = 89)

Learning modality	*N*	*Mean*	*SD*	*F*	*Sig.*	Post-hoc test (Scheffe)
F2F	11	66.82	17.20	3.192*	0.017	(FL) > (OL)*
WF	30	73.43	13.43			
AB	31	72.26	13.86			
OL	6	60.50	12.06			
FL	11	82.73	10.51			
Total	89	72.48	14.37			

* $p < 0.05$

Furthermore, post-hoc Scheffe tests were conducted to detect which pairs of means were significantly different. The mean scores of the FL group were significantly higher than those of OL (FL > OL, $p = .045 < .05$). However, the learning outcomes of participants from the F2F, WF and AB groups did not differ significantly.

Factors affecting the choice of preferred learning modes

To further understand how students used and chose the learning method with open courseware, we analysed the interview data for detailed information.

Students who chose the F2F mode might lack self-confidence in their background knowledge or self-discipline in online learning. Therefore, face-to-face communication with teachers is more practical for them:

> My level in this class is not so excellent, and I am not sure that I can learn this course very well only via online learning. (E01-1F)
>
> I need to have face-to-face classes every week regularly so that I won't give up studying in this course. (E01-1F)
>
> I think the traditional way of face-to-face lessons gives me the sense of security. (E03-3F)
>
> It is more practical for me to go to class with the teacher. I can immediately ask questions face-to-face when I encounter something I don't understand. (E03-3F)

Students who chose the WF mode like to search for information and solve problems they encountered via materials on the course website. Therefore, they have specific information retrieval literacy:

> I always search for the answer from the OCW [open courseware], especially when I meet the difficulties in doing my homework. (E09-2F)
>
> When I prepare for the exam, I just download the lecture slides from OCW and study carefully. I highly recommend the OCW for any college student looking for a helpful tool. (E09-2F)
>
> The searching tool in the OCW is very useful for me to search for my insufficient background in thermal physics. (E06-2M)
>
> When I try to finish my homework, I need to check the other references frequently. Therefore, I can search for the related content from OCW to find the solution. (E06-2M)

Students who chose the AB mode change their learning mode from time to time according to their time management issues:

> If time permits, I hope to be able to study in physical classrooms most of the time. But for some weeks, I will choose to study online, because I am busy preparing for the other subject. (E10-3M)
>
> It is often necessary to switch from one to another. That can be done easier using an OCW to meet my needs. (E27-4F)

Students who chose the OL mode also encountered time management problems. Therefore, they chose online learning, which is more convenient for them:

> Because I have a part-time job, it's easier for me to take the whole course online so that I can manage my schedule flexibly. (E08-4F)
>
> I need to manage my time for learning for this course and others. Online learning is very convenient for me. (E11-2M)

Students who chose the FL mode were fully prepared for the course every week. Therefore, they learned the online course materials first and then interacted with teachers in the physical class:

> I like to learning the online course before I go to the classroom. Therefore, I can know which part if difficult for me and I can pay more attention to it. (E21-4M)
>
> It's beneficial for me to learn the online content first, so I can interact with the teacher to save my problems face to face in the classroom. (E13-5F)

Perceptions of enhancing the thermal physics classroom with technologies, open educational resources and flipped learning

To acquire more feedback on the effects of adopting open online courses in the thermal physics class, we interviewed the course instructor. He indicated that he hoped the students watched the videos before the class rather than after. However, he also indicated that since students were free to choose their learning approach, time management is critical:

> Some students waited till the last minute to watch the videos. In this case, most of them failed the course.

The instructor gave his suggestions on how students should choose their approach to learn. For students with insufficient background knowledge, the traditional face-to-face classroom is essential; on the other hand, students with better background knowledge could watch online videos first and then go to the lectures if necessary:

> I think for the low-achievement students, traditional face-to-face lectures are required. Moreover, the role of online lectures is useful to support students' learning.
>
> In the beginning, I was wondering if the use of open online courses would have any positive effects on students. However, I found that more and more students gave me positive feedback about the online courses.

The instructor also mentioned that he observed that some students had become more active in the classroom due to their previewing of the online courses:

> I could feel the difference with the students who had already watched the online lectures. They were more prepared to ask questions in the classroom.

Discussion

The effects of different learning methods on college students' thermal physics learning compared with the findings of other studies

The conventional classroom is teacher-centred, while the flipped online classroom is video-based, repetitive, and student-centred. Innovative blended-learning models are poised to create a significantly less expensive system. To unbundle teaching and learning in the thermal physics classroom, this study used a mixed-and-adaptive approach to provide students flexibility and alternative patterns. This flexible learning method meets the needs of college students in the Internet generation. During the course semester, students can plan their own schedule independently, instead of taking courses according to the instructor's schedule.

The results indicate that the FL method is more effective than the OL method in terms of students' academic performance. This finding is similar to results from studies by Al-Qahtani et al. (2013) and Sun et al. (2017). Both studies showed that students in the FL group had significantly higher scores than students in OL group. To further explore the reasons, it may be that the learning environment created by the FL method can encourage its learners to have more opportunities to seek external help in the classroom. However, our study finding might be inconsistent with several earlier studies, which found no statistically significant difference in student performance between blended learning and online learning (Hameed et al., 2008; Lim et al., 2019). One possible reason might be that earlier studies focused on blended learning rather than flipped learning. Therefore, we can reasonably speculate that, according to the results of our study, flipped learning supports students' learning more effectively than online learning. Besides, a more appropriate blended learning method should be designed, which can adopt the positive aspects of flipped learning and combine it with face-to-face learning or online learning.

In this study, students could choose their favourite learning modes afforded by the course. Using online technology to expand regular classrooms can promote self-regulated learning. We believe that the advancement of the Internet provides various means to support learning in a more personalised, flexible and on-demand manner.

Conclusions

The findings of this study indicate that IT can transform teaching and learning in the thermal physics classroom, challenge the traditional lecture format, and enable courses to meet student needs. Moreover, we identified five learning modes in a mixed-and-adaptive blended environment, resulting in different learning outcomes. Participants in the FL mode performed significantly better than those who chose the OL mode. The participants who chose the F2F, WF and AB modes did not differ significantly. Each student chose a learning mode based on their time management approaches and personal preferences. As a result of this study, we have reached the following conclusions:

- Open online courses can meet the needs of different kinds of students.
- The flipped learning mode gets the best learning performance.
- Self-regulated time management is the most critical factor for students' learning outcomes.
- For disadvantaged students, it is better to participate in the blended and face-to-face learning modes. For advantaged students, a blended and flipped classroom would be better.

In summary, the mixed-and-adaptive approach adopted in this study seems to provide clear advantages in student time management and performance. This may have resulted from the particular combination of face-to-face learning featuring the presence of an instructor and flipped learning with its flexibility to provide more interaction opportunities between students and instructor. With the emergence of more open online course providers and massive open online courses over the past years, this study provides a valuable reference on how the online revolution can transform traditional on-campus higher education institutions.

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