The impact of flipped classroom andragogy on student assessment performance and perception of learning experience in two advanced physiology subjects

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Submitted 9 September 2019; accepted in final form 27 December 2019

Rathner JA, Schier MA. The impact of flipped classroom andragogy on student assessment performance and perception of learning experience in two advanced physiology subjects. Adv Physiol Educ 44: 80–92, 2020; doi:10.1152/advan.00125.2019.—Flipped classroom teaching has been used by many educators to promote active learning in higher education. This andragogy is thought to increase student engagement by making them more accountable for their learning and increase time on task in the classroom. While there are several systematic reviews that point to improved student results, it remains unclear if flipped classrooms have positive learning effects in physiology education. Flipped classroom teaching was introduced in two advanced physiology subjects (advanced neuroscience, semester 1, and cardiorespiratory and renal physiology, semester 2). Changing the mode of content delivery reduced the time students needed to spend listening to lectures by one-third, without sacrificing either learning content or academic standards. Higher pass rates were observed with larger number of students earning distinction and high-distinction grades. Statistically significant improvements in final grades were observed from both subjects (semester 1: 2017, 49.28 ± 20.16; 2018, 53.29 ± 19.77, \( t_{200} = 2.058, P = 0.0405; \) semester 2: 2017, 58.87 ± 21.19; 2018, 67.91 ± 20.40, \( t_{115} = 2.306, P = 0.023 \)). Finally, students’ perception of their learning experience remained at or above the university benchmarks (median score of >80% for all iterations of the subjects). While the most frequent and persistent area that students suggested could be improved was reduction of content, equal numbers of students commented that no improvement in the subjects was required. Despite the generally positive attitude to recorded didactic teaching content, classroom attendance remained very low, and students did not engage with the active learning content. This suggest that more emphasis needs to be placed on promoting class attendance by developing better active learning content.

INTRODUCTION

The advent, development, and affordability of digital technologies are having a disruptive impact throughout the education sector that is motivating change in teaching practice (5, 12). In the past, the cheapest and most efficient method for transmitting information has been via a traditional lecture, with the expert teaching the student directly and didactically in the classroom. However, the development of new technologies makes it easier for information to be transmitted via internet-based resources. Asynchronous online delivery of learning content via internet-based tools frees up classroom time (synchronous class time) for other, more active learning activities (13, 14).

In parallel to the emergence of internet-based tools for the delivery of learning content, the focus of the educator’s activities has changed from a priority of “what the teacher does” to “what the teacher has the student do” (1, 25). The premise of “active learning” is that students take responsibility for their own learning, and classroom activities are geared toward designing resources that allow students to achieve (master) the specified learning outcomes (3). In a landmark meta-analysis, Freeman and colleagues (13) have shown that, in addition to improving student academic success in STEM (science, technology, engineering, and math) subjects, active learning andragogy also temporarily, at least, improves cognitive skills. When directly testing for metacognition, active learning, in the form of the flipped classroom, has been shown to increase students’ critical thinking, peer learning, and task value, although the authors reported that the improved metacognitive skills were not sustained after 5 mo (39).

Science, technology, engineering, math, and medicine (STEMM) subjects are frequently content heavy (11), and this reflects the epistemology of science and the scientific process (7, 33, 41). Development of knowledge in science is evolutionary in process. The scientific process involves developing and testing hypotheses based on the sum of existing observations in the natural world. At the core of scientific understanding and progress is an understanding of the “what is known” and “what is unknown,” and, for this reason, science subjects are by necessity content heavy (41). This conflicts with practices from the social sciences, which are typically process based (focusing on strategies or procedures associated with learning, rather than the content itself) (3). For this reason, science educators are often reluctant to adopt changes in teaching style.

Flipped classroom design in andragogy (or pedagogy) is intended to capitalize on the emergence of new technology that...
makes delivery of content via internet resources not just possible, but also economical (39). In the flipped classroom model, passive teaching activities are delivered online (or through another medium), which the student accesses in his/her own time (homework), whereas active (student centered) learning activities are completed in the classroom (1, 39).

A recent systematic review by Akçayir and Akçayir (1) showed that 52% of the studies reported improved student learning performance with flipped teaching. Key factors that were identified as leading to the improved student outcomes included the following: increased student satisfaction (18% of reported studies), student engagement (14%), and student motivation (10%). These same authors also noted that 12% of included studies reported that the failure to complete or engage with the out-of-class activities created a significant impediment to the success of the teaching model. In parallel with concerns of failure to engage with the learning content, the students themselves complained that flipped classroom activities were either too time consuming or demanded too much work.

Concerns about students’ perception of their learning should not be understated. For instance, one systematic review (22) identified student self-efficacy in science as a significant predictor of success in bioscience (anatomy, physiology, pharmacology) within nursing programs. A recent paper by Colthorpe and colleagues (10) reviewed the importance of metacognition on student success. The authors identified that self-regulation is a vital ingredient for academic success, with higher achieving students showing better self-regulatory skills.

A meta-analysis of flipped classrooms in medical education, analyzing 46 studies, has found that students have significantly better outcomes compared with lecture-based teaching (8). The evidence of the value of flipped classroom andragogy in either life science (19) or physiology education (16, 26, 35, 38) is more ambiguous. There is some suggestion that any benefit of the flipped class was inconclusive, with the reported data suggesting that any observed benefit was due to a cohort effect rather than the teaching design itself (16). Where a clear positive effect in a flipped class delivery of physiology has been observed, it is possible that the improvement in student performance was a consequence of the introduction of weekly quizzes (holding student accountable for actually engaging with the learning content) rather than the style of content delivery (38). This conclusion was drawn from the student survey reporting that the “quizzes forced a greater than normal preclass preparation” on the students. The same study also reported a very mediocre attitude to the online learning design.

In general, students’ perception of the flipped class is tepid (19, 26, 35, 38). In self-reports of development of metacognitive skills, roughly 50–60% of student responses indicated that flipped class design was a better teaching design for developing these skills (integration of concepts between organ systems, analytical thinking, problem-solving skills, quality of learning), compared with lectures (35). This compares to the 30–36% of students who felt that lectures or flipped made no difference to their deep learning. In a first-year physiology subject, where lectures were removed, but small-class workshops were retained, Page et al. (26) reported that students were ambivalent to online learning, with about one-half of the survey responders demanding a more traditional lecture-based teaching approach.

At Swinburne University of Technology, flipped teaching of advanced physiology was introduced to an advanced neuroscience (focusing on physiology of neuroscience) and cardiorespiratory and renal physiology subjects in 2018. The subject learning outcomes, content, and assessments were substantially the same as per the 2017 delivery, and the units were taught by the same instructors. Here we evaluate the impact of the altered andragogy on student performance in the unit (by comparing the cohort results on assessments in the subjects) and students’ perceptions of their learning (via comparison of the institutional student feedback data).

METHODS

Institutional Context

At Swinburne University of Technology, both advanced physiology subjects described in this paper are taught as electives in the Bachelor of Health Science degree (37). Depending on the major, graduates of this degree often find employment in hospital clinical science laboratories, heart laboratories (ECG and cardiac catheter laboratories), respiratory physiology laboratories (lung function testing), and sleep clinics (EEG), working as clinical scientists/technicians. The advanced neuroscience subject is a required unit in three majors: Neuroscience, Clinical Technologies, and Psychology and Psychophysiology. In addition, advanced neuroscience is service taught as a required subject in the Bachelor of Engineering (Biomedical Engineering). A typical enrollment in this subject is ~150 students, and the subject is offered in semester 1 of each year.

Cardiorespiratory and renal physiology is a core subject requirement in the Clinical Technologies major. It is also service taught as a required subject in the Bachelor of Engineering (Biomedical Engineering). Although advanced neuroscience is not a prerequisite for cardiorespiratory and renal physiology, both advanced physiology subjects are part of the Clinical Technologies major. So most, but not all, students entering this subject have completed advanced neuroscience before commencement of cardiorespiratory and renal physiology in semester 2. Typically, ~60 students enroll in cardiorespiratory and renal physiology, and both advanced physiology subjects have first-year anatomy and physiology as a prerequisite.

Andragogy

The andragogy and assessments used in both subjects are summarized in Table 1.

Common among all instances of the subjects described here were practical laboratory classes. In each semester, six practical classes were scheduled on a fortnightly basis. The aims of the laboratory class activities were to reinforce aspects of the theoretical content and develop skills in clinical applications, experimental techniques, data, and statistical analysis. In each instance, students were expected to write up one practical class activity as a structured abstract [using a modified IMRAD (introduction, methods, results, discussion) format (17, 18)] (see Table 1). In addition to the written report, students’ understanding of each practical class activity, analysis of the outcomes, and conclusion, was assessed via an online multiple-choice quiz the week after the laboratory class.

Another consistent feature in all advanced physiology subjects was a set of revision questions prepared for each lecture. These revision questions were based on the lecture content. They were short-answer questions, with answers discussed or elaborated in the lectures themselves. Students were informed that the revision questions would form the basis of the final summative exam questions, although only a selection of these questions would be chosen. The overt statement of the instructors was that, if a student could answer the revision questions, he/she would be able to answer any question on the final exam. Students were encouraged to work collectively on the revision
Intrasemester quiz or testing
Laboratory-based tutorials
Final exam

Top: advanced neuroscience; bottom: cardiorespiratory and renal physiology. The key change in the subject is the change in didactic teaching presentation from lecture-based teaching in 2017 to online and "chunked" recordings in 2018. In 2018, timetabled class times were devoted to active learning sessions, working either on active learning questions (guided inquiry) or audience response system (Kahoot)-based tutorials. LMS, learning management system.

questions, including discussing possible responses asynchronously on the subject learning management system (LMS) discussion board. In 2018, these questions were identical to those in 2017, except they were referred to as active learning questions (see below).

Academic year 2017. Both advanced neuroscience and cardiorespiratory and renal physiology were taught in a traditional lecture-based, face-to-face mode in 2017. Both subjects had 3 h of scheduled lectures per week, and the principal use of this time was in content delivery. While lecturing was the primary activity in the face-to-face class time, instructors in the subject were very experienced and were effective in engaging the students in active dialogue in the classroom. All lectures were recorded via Echo360 lecture capture (https://echo360.com/) and were available to the students asynchronously via the LMS. Prior to the lectures, a student handout, typically the slide presentations for the lecture, was available to students via the LMS.

An additional 1-h tutorial was scheduled fortnightly, from week 3 onwards (5 in all), in advanced neuroscience in semester 1, 2017. These tutorials were conducted in a large lecture theater, one instructor for the entire cohort. Instructors decided to exploit a web-based audience response system (Kahoot, https://kahoot.com/) to promote student engagement in the tutorials. Typically, a 50-min tutorial consisted of eight Kahoot multiple-choice questions, with students given 1 min to respond via the web-enabled device. Instructors then had the opportunity to diagnose difficult or misunderstood concepts, based on student responses to the questions, and time (5–10 min) could be spent exploring these difficult ideas. Tutorials were not lecture recorded.

In semester 2 (cardiorespiratory and renal physiology), although face-to-face classes were planned to be lectures, due to personal circumstances of one of the instructors, it was necessary that 6 h of lectures (across 3 wk, 1/6th of the lectures) in the third quarter of the semester be recorded in advance, and the lectures were canceled. Prerecorded lectures were broken into short vignettes of between 5–20 min duration (chunking) and made available to the students through the Echo360 streaming server and hyperlinks on embedded in the LMS. The generally positive response from students about the chunked lectures encouraged the teaching staff to undertake the flipped andragogy.

Throughout the semester, instructors estimate approximately one-third of enrolled students consistently attended the face-to-face classes.

Academic year 2018. In 2018, teaching staff in the advanced physiology subjects decided to flip the teaching (1, 16, 19). The general subject design was modeled on previous work from one of the instructors (26, 29). Timetabled classes were broken into a 2-h session and a 1-h session per week (total face-to-face timetabled time was 3 h/wk × 12 teaching weeks).

The overall content for the subjects did not change between years, and the same PowerPoint slides were used in both iterations of each subject. In 2018, however, lectures were recorded in advance of the timetabled class. Screen capture with spoken voice over recordings were made (Camtasia 9, TechSmith, Okemos, Michigan), and MP4 files were produced. The MP4 files were then loaded to the Echo360 Streaming Server, and hyperlinks to the recordings were embedded.
into the LMS. Each recording was intended to address a single learning concept for the lecture, which allowed instructors to chunk recordings into 5- to 20-min vignettes (see Table 2). Screen capture presentations were typically made on a just-in-time model, so, in the first iteration of the flipped subjects, little additional production value was added to the recordings.

The original intention was to use the freed-up 2-h teaching block for team-based “guided inquiry learning” workshop, and the 1-h session was used for audience response system-based (Kahoot) tutorial activity, as described for advanced neuroscience in 2017. Students were advised to watch the screen captured recordings for the week before attending the workshop for that week. As they watched the recordings, the students were encouraged to work on the active learning questions in parallel. At the outset, the plan was for students to then attend the 2-h workshop, form small teams, compare answers to the active learning questions, and engage in peer-to-peer discussion of contentious responses or concepts. Peer-to-peer learning has been shown to improve student performance in physiology (28) and increases conceptual understanding of the subject content (25). In addition, asking students to work on the problems collectively promotes effortful learning and recall retrieval, both cognitive activities that improve learning (15). Peer-to-peer learning also improves students’ metacognition about their learning experience (34), which is another cognitive learning strategy for improving the learning (15).

Peer-to-peer instruction can also be viewed as a form of elaboration, which helps consolidate learning content (40).

To facilitate the workshops, three high-performing (high distinction) undergraduate students from the 2017 cohort were invited to attend as undergraduate teaching assistants. The students who volunteered as undergraduate teaching assistants viewed attending the class as an opportunity to consolidate and revise their own understanding of the advanced neuroscience subject as they pursued their capstone studies in the neuroscience major. At the same time, their closer proximity to the students enrolled in the class simultaneously acted as social cues for the enrolled students and afforded a more relatable explanation of much of the learning content (27). No special training was provided to the undergraduate teaching assistants. The undergraduate teaching assistants were instructed to circulate through the class and discuss the student progress with the active learning questions. The undergraduate teaching assistants would inform the instructor in the room of any common or persistent questions that emerged, and the instructor could then address the question with the entire class using a whiteboard presentation.

In practice, students rejected the team-based learning workshops. In the first week ~50% of students attended, declining to 30 students by the second week, and by midterm only 5 students were attending the workshop. At this time, the teaching team abandoned the team workshop in favor of a student-led discussion for the remainder of the semester. Students were invited to “stump the lecturer”: they could ask any content-related question to which the lecturer would then respond in a whiteboard presentation. The “stump the lecturer” workshop was retained in semester 2, where workshop attendance was maintained consistently at ~20 students per week.

Assessment. Only minimal changes in assessments were made between 2017 and 2018, driven by institutional assessment policy (36). The assessment structure of the units is summarized in Table 1.

FORTNIGHTLY TESTS. Recall retrieval or test enhanced learning has been shown to improve learning, knowledge transfer, and higher order learning (15, 40). Regular quizzing is seen by students as an authentic and effective tool for promoting consistent study and learning through the teaching period (26). Online quizzes were delivered via LMS. These were treated as “take home tests.” Students were told that “cheating was expected,” i.e., the test should be completed in an open-book fashion, and discussion between students about the question was encouraged. Questions on the quiz were randomly selected from a bank of questions (at least three times as many questions in the question bank as were presented on the quiz) and where possible the order of answers and distractors was randomized. The quiz (6–10 questions) was available to the students for 1 wk and was timed for completion within 1 h. Students were allowed two attempts at the quiz, with the expectation that they would use the feedback from the first attempt to guide their study before they attempted a second time.

In practice, most students started attempt 2 immediately after completing attempt 1, thus not utilizing the formative assessment purpose of the quizzes.

PREPRACTICAL CLASS READING. In 2017 and semester 1, 2018, 5% of the subject grade was earned for attending laboratory classes. The rationale was that 1) development of physiological measurement and laboratory skills was a subject-intended learning outcome; and 2) these subject learning outcomes could not be achieved without attending the laboratory classes. In cardiorespiratory and renal physiology, semester 2, 2018, class attendance was replaced with a laboratory class prereading activity. Although the practical class reading did not change between 2017 and 2018, students were assessed on having completed the preworkshop questions embedded in the reading activity.

FINAL EXAM. The final exam was a summative assessment of the entire semester. For 2017 and semester 1, 2018, the final exam was valued at 50% of the subject total. In semester 2, 2018, the final exam was weighted at 45% of the final mark. Questions on the exam were short-answer responses and selected from the active learning questions on which the students were working throughout the semester. The exams were moderated by a colleague not associated with the teaching and verified for suitability and consistency of standards.

Statistics

All statistical analysis was performed in Prism 8 (GraphPad Software, Inc.). Data are presented as means ± SD, unless specified as median.

Human Ethics

This research has been approved by the Swinburne University Human Ethics Committee (SHR Project 2019/204).

RESULTS

Learning Content

Recorded learning content. In 2017, each of the advanced physiology units was taught in a traditional lecture format. These included, in both semesters, 3 h of lecture per week over 12 wk, leading to a total of 36 h of lecture content. Personal observations from the lecturers (the authors) were that the lectures were interactive discussions; however, the vast majority of the teaching time was didactic. In addition to the 36 h of lecture, in the advanced neuroscience subject, an additional 5 h

Table 2. Time commitment expectation from students to engage in online content in the flipped learning model

| Advanced Neuroscience | Cardiorespiratory and Renal Physiology |
|-----------------------|---------------------------------------|
| Total hours of recording | 23 h, 38 min | 22 h, 21 min |
| Total no. of recordings | 172 | 128 |
| Average length of recording | 8 min, 56 s | 10 min, 30 s |
| SD of average length | 4 min, 11 s | 5 min, 18 s |
| Average no. of recordings per week | 14 | 11 |
| Average time commitment from students | 2 h, 8 min | 1 h, 56 min |
(1 h every fortnight) was timetabled for “tutorials.” There was a single tutorial scheduled in a large lecture theater for all 139 students enrolled in the subject. These tutorials were “active learning” sessions; the instructors exploited a web-based gamified audience response system (Kahoot, https://kahoot.com/) to quiz students (8–12 questions per session), with appropriate time dedicated to explanation of misconceptions or errors that were revealed by the game.

Prerecording and chunking the lectures in 2018 reduced the time for content delivery in both subjects by one-third (Table 2). The reduced time for content delivery occurred without changing the lecture content or lecture slides between years. Regardless of students’ perception of the recorded content (see below), “flipping” the class reduced the student workload. On average, students should have allocated ∼2 h each week just for watching the recorded lecture vignettes. The typical length of recordings was between 8 and 11 min, with the longest recording being 20 min and 40 s long (Table 1). The longest recordings addressed complex topics like the mechanism underlying the cardiac action potential and the regulation of intracellular calcium during cardiac myocyte contraction.

Active learning question (revision questions). In each of the classes, there were typically between 9 and 11 revision questions per 1 h of timetabled lecture (i.e., 36 h of lecture per semester). The actual averages were 9.6 questions for cardiorespiratory and renal physiology (CR&R), and 10.33 for advanced neuroscience (AN). This averaged out to 28.75 (CR&R Physiology) and 31 (AN) revision (or active learning) question per week across the 12-wk teaching semester. In all, students in the advanced neuroscience subject had 372 questions in their study guide, whereas the cardiorespiratory and renal physiology students had 345 questions. This averages out to ∼1 question for every 3 min of recorded content throughout the semester. Students were instructed that the final summative exam would comprise questions from these question banks.

Student Performance on Assessment

Advanced neuroscience. Students in the advanced neuroscience subject performed significantly better in the units in 2018 (53.29 ± 19.77, n = 138) compared with 2017 (49.28 ± 20.16, n = 132) (t_{196} = 2.058, P = 0.0405) (Fig. 2D). In 2017, 44% of students failed the subject, whereas, in 2018, 37% of student failed (Fig. 1A). At the same time, the proportion of students scoring distinction or high distinction rose from 18% in 2017 to 25% in 2018 (Fig. 1A).

The differences in the final grade for the advanced neuroscience unit is attributable primarily to improved performance in the practical laboratory report (2017: 60.92 ± 18.36%, n = 114; 2018: 77.05 ± 14.07%; t_{124} = 7.802, P < 0.0001) (Fig. 2A). The midsemester assessment in advanced neuroscience changed between 2017 and 2018 (see Table 1). In 2017, two high-takes summative midsemester tests were completed online, each worth 7.5% of the subject total mark. The combined average for the two tests was 70.4 ± 18.98% (n = 134). In contrast, during 2018, more frequent (5 fortnightly), lower stake formative tests, each worth 3%, were completed. Students averaged a total of 68.49 ± 20.51% for these tests. There was no statistical difference in the performance of the students in the midsemester tests (t_{284} = 0.94, P = 0.35). Notably, students were allowed two attempts at each test in both years, although it was unlikely that any one student received the same set of questions (due to question pool randomization) (Fig. 2B).

Cardiorespiratory and renal physiology. Students in the cardiorespiratory and renal physiology subject in 2018 outperformed students in the 2017 iteration of the unit (2017: 58.87 ± 21.19, n = 59; 2018: 67.91 ± 20.40, n = 54; t_{108} = 2.306, P = 0.023) (Fig. 3D). Twenty-one percent of students failed the unit in 2017. This contrast with a 6% failure rate in 2018 (Fig. 1B). Similarly, only 29% of student scored either a distinction or high distinction in the subject in 2017 compared with 61% of students scoring those grades in 2018.

The improved student performance in the unit was accompanied by improvement in the exam performance in the subject (2017: 43.42 ± 23.83%, n = 53; 2018: 61.48 ± 21.02%, n = 48; t_{90} = 4.022, P = 0.0001) (Fig. 3C). There were statistically significant increases in the practical report assessment (2017: 67.09 ± 19.32%, n = 53; 2018: 79.13 ± 12.24%, n = 484; t_{90} = 3.693, P = 0.0004) (Fig. 3A). In both 2017 and 2018, students completed fortnightly (formative) assessment quizzes (Table 1). Students in 2018 outperformed their 2017 counterparts by ∼13% (2017: 60.66 ± 21.70%, n = 61; 2018: 73.76 ± 21.16%, n = 55; t_{115} = 3.29, P = 0.0014) (Fig. 3B).

Student results on prerequisite first-year anatomy and physiology. To control for the possibility that any improvement of results in the advanced physiology subjects was due to a cohort effect, we looked to see if the overall student performance in a prerequisite anatomy and physiology subject was different over
the previous four iterations of that subject. First-year anatomy and physiology is a compulsory subject in the degree and is taught in both semesters 1 and 2 of each year. No statistically significant difference ($F_{3,694} = 2.351, P = 0.071$) was seen between any of the four previous iterations of the subject, suggesting that a cohort effect cannot explain any improved results in the advanced physiology subject (Fig. 4).

Students’ Perception of Their Learning Experience

Quantitative institutional student feedback of subject. The end-of-semester institutional student feedback report is divided into a quantitative part made up of three questions and a qualitative component of two questions. The quantitative report asked students to rate aspects of the student experience based on a 10-point scale, reflecting how strongly students agreed or disagreed with a statement, with 10 suggesting that they strongly agreed with the statement and 1 indicating that students strongly disagree. Thus higher scores indicate greater student satisfaction with the subjects’ overall design and teaching. A single score out of a maximum of 30 (3 questions $\times$ maximum of 10 response) could be calculated. Unfortunately, two of the questions on the survey changed between 2017 and 2018, making direct comparisons between the quantitative analysis difficult.

While much of the qualitative feedback for both subjects (Table 3) suggests that students were disgruntled with the lack of lectures and perceived workload, this was not reflected in the quantitative response, which remained at or above the university median. In 2017, both advanced neuroscience (median score = 26/30) and cardiorespiratory and renal physiology (median score = 27/30) quantitative student feedback exceeded the university whole score (semester 1 median score = 24/30, semester 2 median score = 24/30). In 2018, the year that the flipped andragogy was implemented, students’ perception of the learning experience in each of these subjects experienced a small decline, although they continued to equal
that of the typical subjects offered at the university (advanced neuroscience, 24/30; university semester 1, 24/30; cardiorespiratory and renal physiology, 25/30; university semester 2, 25/30). Overall scores of >80% (24/30) indicate consistent and sustained high satisfaction with the subjects, regardless of andragogy.

Separate institutional feedback of teaching was provided to the individual instructors in the unit but was not analyzed for this study.

Qualitative analysis of institutional student feedback of subject. Thematic analysis of the responses to the qualitative feedback of the institutional student feedback are summarized in Table 3. In response to the prompt, “Areas that could be improved” across the four semesters of analysis, the two most consistent responses were “Too much content” (16.5 ± 4% of responses) and “No improvement required” (17.5 ± 10.3%). When the flipped classes were introduced in 2018, an average of 16.5 ± 2.8% of the responses suggested regular lectures would improve the subjects, whereas 8 ± 4% of responses suggested fewer active learning questions. Examples of the comments provided in the student feedback in response to the “Areas that could be improved” prompt can be seen in Table 4.

Positive aspects of the subjects’ andragogy were prompted by “The best aspects of the unit were” (Tables 3 and 5). Overwhelmingly, the most positive attribute of the two subjects in each of the semesters of teaching was the teaching staff (23.5 ± 15.5% of responses). Considering the generally positive attitude toward the teaching staff, it is notable that, in the first iteration of the flipped class (semester 1, 2018, advanced neuroscience) only 5% of the comments mentioned “teaching staff.” This contrasts with 42% of responses mentioning teaching staff for the same subject in 2017.

Fortnightly quizzes were also constantly viewed as a positive aspect of the four semesters of teaching (10.8 ± 9% of responses). This average was skewed by an overwhelmingly positive attitude to the quizzes in semester 2, 2017 (24% of responses). The general popularity of regular, low-stakes quizzes as a formative assessment tool is consistent with other studies (26, 30). Students perceive the regular quizzes as motivating them to remain up to date with the learning content.

Fig. 3. Violin plots of assessment and final grades for cardiorespiratory and renal physiology subject. A: written practical report (structured abstract). B: fortnightly tests (both years). C: final exam. D: final subject mark. Note that A–C are expressed as a percentage of the grade value (see text for details). Dashed lines are mean, and dotted lines are SDs. All statistics were performed using a Student’s t test, with a two-tail design.
and as good and timely feedback of their understanding (see Table 5).

Kahoots were used in tutorials in three of the four semesters of teaching. Typically, $8.7 \pm 1.2\%$ of the student responses emphasized the audience response system-based tutorials as positive aspects of the subject. Consistent with the positive attitude toward the Kahoots, in semester 2, 2017, cardiorespiratory and renal physiology, when there were no Kahoot-based tutorials, 13% of the responses in “Areas that could be improved” requested Kahoot-based tutorials.

Fortunately, in teaching physiology, teaching staff are teaching material that is not only intrinsically fascinating but also readily applicable to any student who has an active interest in pursuing human health-related vocations. For this reason, it is not surprising that, between semester 1, 2017, and semester 1, 2018, $8 \pm 2\%$ of students typically identified the content of the units themselves as “best aspects of the units.” Content could include the intrinsic interest in the subject, but also includes intellectual challenge and style of teaching presentations (see Table 5 for expanded comments). The positive response to the subject content stands in contradistinction to the student criticism of too much content.

In response to the flipped class prerecorded content, there was overwhelming endorsement of chunking the recordings (27.5 ± 6.4% of responses, Table 4). The positive response to chunking the recorded content made the content easier to find and more accessible (Table 5). Student comments also indicated that they felt the vignettes meant that they received clearer and more detailed explanations of the material (Table 5).

![Figure 4](https://example.com/figure4.png)

**Fig. 4.** Results in first-year anatomy and physiology subject. Note that there is no statistically significant difference between the cohorts entering advanced physiology. Dashed lines are mean, and dotted lines are SDs (one-way ANOVA, $P < 0.05$).

Table 3. **Thematic analysis of the qualitative comments on the institutional student feedback reports**

|                           | Advanced Neuroscience 2017 | Advanced Neuroscience 2018 | Cardiorespiratory and Renal Physiology 2017 | Cardiorespiratory and Renal Physiology 2018 |
|---------------------------|---------------------------|---------------------------|-------------------------------------------|-------------------------------------------|
| **Areas that could be improved** |                           |                           |                                           |                                           |
| Total no. of commenters   | 48/53                     | 61/72                     | 23/27                                     | 22/27                                     |
| Too much content          | 6 (13)                    | 14 (22)                   | 4 (17)                                    | 4 (18)                                    |
| Lectures too fast         | 3 (6)                     |                           | 1 (4)                                     |                                           |
| Hard to catch up if you fell behind |                 |                           |                                           |                                           |
| Poor LMS organization     | 6 (13)                    |                           |                                           |                                           |
| Tutorials (more frequent, smaller classes, not audience response system) | 8 (17) |                           |                                           |                                           |
| Audience response system-based tutorial (to be included) | |                 |                                           |                                           |
| Fewer active learning questions | 3 (5)                     |                           | 3 (13)                                    |                                           |
| Regular lectures          | 14 (22)                   |                           | 3 (14)                                    |                                           |
| Laboratory classes (more time, better organization) | 5 (8) |                           | 3 (13)                                    | 9 (41)                                    |
| Fortnightly quizzes (too many, too rigid deadline) | 5 (8) |                           |                                           |                                           |
| Staff-student communications (lecturer too aloof) | 3 (5) |                           |                                           |                                           |
| More comprehensive lecture handouts | 5 (10)                     |                           | 3 (13)                                    |                                           |
| Other                     | 6 (13)                    | 4 (6)                     | 7 (30)                                    | 6 (27)                                    |
| No improvement required   | 10 (21)                   | 12 (19)                   | 2 (9)                                     | 3 (14)                                    |

| **The best aspects of the unit were** |                           |                           |                                           |                                           |
| Total no. of commenters   | 30/53                     | 43/72                     | 18/27                                     | 17/27                                     |
| Online/chunked lecture content | N/A                       | 20 (48)                   | 1 (6)                                     | 7 (41)                                    |
| Lectures                  | 6 (20)                    |                           | N/A                                       | N/A                                       |
| Audience response system-based tutorial | 3 (10)                     | 5 (128)                   | 3 (18)                                    |                                           |
| Fortnightly quizzes        | 3 (10)                    | 3 (7)                     | 6 (33)                                    | 2 (12)                                    |
| Active learning questions  | 9 (21)                    |                           |                                           |                                           |
| Laboratory classes (reinforced understanding of concepts/ relevant to work) | 8 (27) | 7 (17) | 7 (28) | 6 (19) |
| Teaching staff (engaging, motivating, depth of knowledge) | 15 (50) | 3 (3) | 7 (39) | 6 (35) |
| Content                   | 6 (14)                    |                           | 2 (11)                                    | 2 (12)                                    |
| Other                     | 1 (3)                     | 9 (21)                    | 2 (11)                                    | 2 (12)                                    |

Raw values represent absolute number of comments that were scored to the theme, with the percentage value in parentheses, which represents the proportion of students who commented. LMS, learning management system; N/A, not applicable.
Table 4. Example extended answers to the prompt “Areas that could be improved” on the institutional student feedback reports

| No. | Answer |
|-----|--------|
| 1. | “I found there was way too much content for this unit and was really overwhelmed. . .” |
| 2. | “If online lectures is [sic] the only way to move forward, then at least some of the content should be reduced, or at least it should be ensured that if the lecture time is 2 h, the online content should not be more than 2 h as well.” |
| 3. | “If the content was condensed into more important aspects rather then [sic] bringing it out with too much content . . .” |
| 4. | “There is FAR too much involved in this unit. The amount of content is virtually impossible to keep on top of and then there’s active learning sessions, kahoots, laboratories, quizzes, laboratory logsheets, an assignment and an exam on top of that. The content covered in this unit could easily be spread across three different units and to try and keep on top of it in one semester has been at the very least challenging and at worst, verging on a full blown mental breakdown.” |
| 5. | “With so many active learning questions, I found the majority of my time was taken up with answering them, not comprehending and learning the information. It makes it difficult to understand what is the main focus of each week/module. I would prefer if there was [sic] perhaps 20 core questions for each week and then supplementary questions for additional help.” |
| 6. | “Too many Active Learning questions, which meant I spent more time on this unit than I should have.” |
| 7. | “Flipped learning is a lazy excuse for teaching and learning. If you honestly think that it’s a good method of learning or teaching you have never had a good teacher.” |
| 8. | “Instead of an in person kahoot/quiz, I would definitely benefit from an interactive class lecture, which would also in turn get through some of the content quicker and more efficiently.” |
| 9. | “I really didn’t like the online lecture aspect of this unit. I realize that a lot of students miss lectures and prefer to watch them online, but there are students, including me, who prefer face-to-face lectures. I always make sure that I attend every lecture and tutorial for each of my subjects, so it doesn’t seem fair that I’m being denied the opportunity to come to lectures when I’m paying for it. Online lectures give me no motivation to watch them, and the only result is that weeks of lectures are piled up in the end.” |
| 10. | “I wish that we were told the exam is not that hard so I wouldn’t have spent so much time revising the things we were told in the 2 h lectures” |
| 11. | “Either make the unit online-based or make it classroom based. I loved the idea of pre-recorded lectures, the only think I found difficult is recorded classes to be better organized. having 6 stations and only two tutors to help held up a significant amount of the class time waiting for assistance. This could be better done by having 2–3 stations, or more tutors in the class. . . Two hours was too short for a proper practical to be completed and all questions answered. Not much time was allocated to the prelab before the prac got started, leaving little room for questions.” |
| 12. | “Laboratory classes (more time, better organization)” |
| 13. | “Lecture slides (notes). It would be helpful if the slides had more information on the topic. Most of them make very little sense and need (Lecturer) to go into details.” |
| 14. | “Too much content” |
| 15. | “Fewer active learning questions” |
| 16. | “Regular lectures” |
| 17. | “More comprehensive lecture handouts” |
| 18. | “No improvement required” |
| 19. | “Other” |
| 20. | “I found it challenging to keep up with both the recorded material and class attendances. Almost like double the workload compared to other units.” |

Exemplars are divided by thematic analysis.

**DISCUSSION**

Flipped learning is a lazy excuse for teaching and learning. If you honestly think that it’s a good method of learning or teaching you have never had a good teacher. My theory is that somebody decided that if they record all the lectures, write up all the questions based on these lectures and then upload it all, not only can they upload them with slight revisions each year essentially removing all the work behind it, but also it’s a lazy work ethic and it’s a dumb waste of resources. Also the amount of work each week is way over the top. In theory doing 12 hours of work for one subject a week is way too much. As somebody who is studying a lot harder subjects, I’ve been told that if you can get an hour for each contact hour that’s great. Doing 12 hours of work by four, so forty-eight hours a week of University work, as well as living out of home independently, working and basically running myself into the ground for 13 weeks isn’t worth it. The tests for the modules are dumb. . . Doing weekly tests is boring and crap. I don’t feel as though I’m learning as it’s just another heap of crap to do. Honestly, just scrap the whole unit. Take a long hard look at the labs, the tests, the content and ‘flipped learning’ and just get rid of it. This unit is probably the worst that I’ve undertaken. Congratulations. (Student feedback of subject comments, advanced neuroscience, 2018)

Prerecording and chunking the lectures up reduced the time students were expected to spend on teaching activities by about one-third. In addition, chunking the lectures made the teaching content more accessible and, in theory, made it easier for students to manage their own workloads. For instance, a typical
week in the advanced neuroscience subject had 14 prerecorded lecture vignettes, with an average length of 9 min, and equates to 2 h of didactic teaching content a week. At the start of the semester, students were encouraged to set aside 0.5 h each day in the morning and again in the afternoon for 5 of the 7 days of the week (5 h of time dedicated to the subject, see Table 6). If we assume that students spent 1 h on weekly quiz (assessment related) activities, instructors in the course expected students to spend 4 h/wk on self-directed learning activities (blocked into 30-min sessions). This compares favorably with the university’s student workload policy, which stipulates that each subject have an “average total of 150 hours of student workload” (36).

Table 5. Example extended answers to the prompt “The best aspects of the unit were” on the institutional student feedback reports

| No. | Answer |
|-----|--------|
| 1.  | “Having the online lectures split into smaller blocks made it easier to start and come back to them. The breakdown of each concept was done in a lot of detail so it made the difficult content easy to understand.” |
| 2.  | “Chunking of echo recordings!! YES!!! Super, super, super!!!!!” |
| 3.  | “The prerecorded lectures and the activity questions.” |
| 4.  | “The tutes with the Kahoots, they were great for revision and they were really engaging.” |
| 5.  | “Fortnightly tests are the best, because they encourage students to study…” |
| 6.  | “The lecturers are the best—the contents are precise and to the point. The lecture notes, the pre-recorded lecture video presentations, the active learning questions, the Kahoot! all are very interesting and motivating. The best aspect of this unit is the lecturers’ ability to interactively and logically explaining the concepts underlying physiology, they makes [sic] it easily understandable using [their] deep knowledge of physiology.” |
| 7.  | “There was a lot to love in this unit. I found the lecture content to be incredibly fascinating, and it built extremely well on first-year anatomy content. The lectures were engaging, and [teaching staff] made a concentrated effort to explain more challenging topics in ways we could visualize and understand. The weekly Kahoots session was often the highlight of the week, and [teaching staff] took care to explain every concept in fun and engaging ways. I often reflected on what I learned in Kahoots when revising content, simply because the Kahoots sessions stood out. The practical sessions were also a great learning tool, and it was great seeing the content we were learning in action. I feel like this unit will stand out in my academic career, and that the skills and knowledge I attained here will greatly benefit my future.” |
| 8.  | “According to my understanding, the pre-recorded lectures is a relatively new concept adopted by [teaching staff] so I would like to offer my feedback. I thought they were very helpful and I think this is something that should be continued in the future. I am very satisfied and I really appreciate [teaching staff’s] hard work through the enormous time and effort he puts to every lecture every Kahoot every online test etc. (This is the only unit where the answers of the online tests were nowhere on the internet; therefore it is obvious that he puts a lot more work than every other lecturer I had for the weekly online tests).” |

Exemplars are divided by thematic analysis.

Table 6. Predicted student workload and time on task during each semester

| Task                              | Time on Task |
|----------------------------------|--------------|
| **Self-directed learning activities (weekly)** |              |
| Didactic learning activity       | 3 h/wk       |
| Active learning questions        | 2 h/wk       |
| Weekly quiz activity             | 1 h/wk (×10 wk) |
| Time per semester                |              |
| Total Across the Semester        | 36 h         |
| **Classroom-based activities (weekly)** |          |
| Active learning session          | 2 h/wk       |
| Kahoot quizzes                   | 1 h/wk       |
| Practical classes                | 2 h/fortnight |
| Time per semester                |              |
| Total Across the Semester        | 24 h         |
| **Other subject-related activities** |            |
| Practical class prelaboratory activity | 15 min/fortnight |
| Practical class data analysis    | 1 h/fortnight |
| Practical class support research and write up | 4 h/semester |
| Total “other” semester-related activities |              |
| SwotVac study                    | 16 h         |
| Time on subject                  |              |
| Estimated time per week (×12 teaching weeks) | 145.5 h    |
| Student workload policy (per semester) | 11 h      |

Note the course activities were designed on the basis of the University’s student workload policy of 150 h of student work per semester per subject, taught across a 12-wk teaching semester.
“Too much content” is a frequent criticism of physiology subjects (21). Flipped andragogy places more responsibility on the students to be self-motivating and self-regulating in their learning, since there is an explicit expectation that students need to engage with the content in a self-directed learning environment (1). Thus the perception of excessive content is exacerbated in the flipped classroom (1, 38). Nevertheless, the concern about student perception of too much content, or the subject workload, may be out of proportion to actual student perception. When directly surveyed about learning content, 60% of students in a first-year allied health physiology subject reported that they thought the quantity of material available to support their learning was appropriate, whereas approximately one-third of the responses suggested that there was too much content (410 total respondents, >90% of enrolled cohort) (26). In this study, across all instances of the subject, <25% of comments (between 4 and 8% of enrolled students) complained about too much content. Thematic analysis of “Too much content” included that too much time was required to complete the online learning tasks. Nevertheless, retrospective analysis of the learning resources reveals that recording and chunking the lecture content reduced the time commitments required from students by approximately one-third. This is consistent with previous reports (35).

Lab work and flipped learning. Although I struggled last semester in Neurophysiology—which had the same structure—I realised [sic] that it was my own fault I struggled, and taking on board the flipped learning this semester I feel I thrived. (Student feedback of subject comment, cardiorespiratory and renal physiology, 2018)

With students opting not to attend the face-to-face learning sessions (either lectures or active learning workshops), the students’ approach to learning is probably more similar to online only, rather than a blended learning design. Broadbent and Poon (6) have recently explored the metacognitive approach that students use in an online environment, and the impact these have on academic outcomes. Analysis of 12 studies suggest that metacognitive skills have smaller impact on academic success in an online environment compared with a traditional teaching scenario. One possible conclusion from this is that, whatever the expected advantages from a flipped class andragogy on students’ self-regulated behavior (see Ref. 39), these are lost when students do not engage in the “active learning” (i.e., face-to-face) component of the subject (see Ref. 1). Previous reports have shown that fully online subjects have no advantage, in terms of student performance, compared with more traditional subject design (23). In choosing not to attend face-to-face classes, the students disadvantage themselves. They are negating the purported benefits of the flipped teaching model. In part, it is incumbent on the instructors to design active learning activities that are relevant and engaging, that make the student want to attend class, and that are transparently beneficial to the students. It is clear that, in the first instance of the flipped advanced neuroscience subject, we (the instructors) failed to convince the students of the intrinsic value of the active learning sessions (for instance see quote 9 in Table 4). Student feedback comments about the intended “team-based” problem solving at the outset reflected frustration that, if students failed to complete the initial online tasks before the workshop, working on their own (i.e., student-led activities in class) was time wasted, since they felt they could make no progress. There was a perception in their minds of something inauthentic about using the class time to collectively work on the active learning questions. There was always a trepidation that their collective answers would be incorrect.

In previous versions of the flipped classroom, there were three significant attributes that may have contributed to their overall success (26): 1) small class size for the active learning sessions (workshops); 2) entry tickets (preworkshop quizzes); and 3) exit tickets (some form of team submission). Rather and colleagues (26, 29) have previously argued that preworkshop quizzes make the students accountable for arriving at class prepared to engage in the team learning activity. Having an assessable team submission at the end of each workshop effectively made attendance mandatory. Finally, small class sizes afforded teaching staff the opportunity to meaningfully engage with students as small groups or individuals. More recently Megaw and colleagues (24, 42) have observed that students with high tertiary entrance rank (academically well-prepared students) saw only modest improvements in their success in Physiology in a flipped classroom model. The greatest success was seen in students with lower university entrance scores (42). Crucially, however, these authors observed the greatest benefit to the learning experience was not due to the altered content delivery, but as a result of a clear focus on well-designed in-class active learning activities and in-class quizzing, making attendance a requirement of assessment (24).

In the scenario described here, the active learning workshop was in the large lecture theater, with one instructor for the whole cohort. Recognizing that this would mean that a single lecturer in the classroom could not effectively engage with so many groups, we reached out to students from the previous year to assume the role of undergraduate teaching assistants. However, given the ad hoc nature of this strategy, we did not adequately train them for the task (27). In this context, it is interesting to note that, while face-to-face class attendance diminished to only 5 of 127 enrolled students in advanced neuroscience by the end of semester, during semester 2 cardiorespiratory and renal physiology, the face-to-face classes were more popular and had higher student attendance (~50% of the student cohort of 48 students; authors’ personal observations). A number of reasons can explain this. While a better timetable allocation for the second semester subject (i.e., lectures in the middle of the day rather than at 8 AM in the morning) and students with better experience in flipped classroom learning may explain the more consistent attendance, it is also possible that the change in classroom activity may contribute. “Stump the lecturer” gave students an explicit opportunity to raise questions about content. Although this somewhat reverted to a teacher-centered environment, it was seen by the students as a more authentic learning experience (hence the greater attendance). From the instructors’ perspective, it retained attributes of active learning: the students directed the content of each class by asking questions about areas of the content that were conceptually difficult. Stump the lecturer still required the students to engage with the online content—how else could the students formulate their questions. Simultaneously it allowed the students to remain in their comfort zone.
Team-based learning has been shown to improve student satisfaction, increase student engagement, and improve assessment results in medical and allied health training (31). Peer-to-peer teaching (perhaps considered a form of team-based learning) has been reported to increase student satisfaction and assessment outcomes in undergraduate physiology (34). Student reflection of peer teaching indicated that students found the expectation to perform as an instructor motivating and improved self-directed learning. Student reflection on their own approach to learning reports improved meta-cognitive reflection on their understanding, since they might have been expected to assume the role of instructor. Quantitative analysis of team-based learning has also shown the greatest benefit of the team approach was for the students at greatest risk of failing (28).

The andragogical advantages of team-based learning justify persisting with the strategy. The key hurdle is getting students to engage and to see the time as an authentic use of class time. Part of the problem is potentially institutional. Universities signal to the students what they think is important by what they make compulsory, designated hurdle activities, or what is assessed. By making lectures or face-to-face class attendance voluntary, and by prohibiting assessment-related activities that would make class attendance required, universities retard the ability for educators to achieve good educational outcomes for students. Tune et al. (38) have demonstrated that weekly in-class quizzes produce positive learning outcomes. A simple formative assessment task like asking students to reflect on the “known-knowns” and “known-unknowns” about the week’s content that needs to be completed in class may provide enough motivation for students to attend, and encouraging students to engage in these reflective practices has been shown to improve learning performance (6, 10).

Without question, the fail rates in advanced neuroscience are unacceptably high. What is interesting to note, however, is the much greater success in the second-semester cardiorespiratory and renal physiology. As the cardiorespiratory and renal physiology student quoted in the discussion above suggests, experience in semester 1 informed the behavior in semester 2, resulting in better engagement and enhanced learning. A meta-analysis by Freeman and colleagues (13) has reported that, in a traditional STEM subject, there is an average fail rate of 33.8%. This falls to 21.8% when active learning strategies are adopted. Crucially, the magnitude of improvement seen is class size dependent, with the greatest improvement seen in classes of fewer than 50 students, and only small improvement seen in classes greater than 110 students. Our observations would support these findings.

It is hard to interpret the outcomes of the midsemester test for the advanced neuroscience subject due to the changed assessment structure between 2017 and 2018. While both iterations of the subject relied on what is essentially take-home tests, delivered online and open for an extended period of time, the change from two summative midsemester tests to fortnightly formative quizzes hinders the interpretation of a lack of improvement in testing. The rationale behind changing the assessment to the fortnightly tests is supported by cognitive learning theory, which suggests that retrieval practice (or test-enhanced learning) improves long-term retention of concepts, leading to better learning outcomes (40). Frequent, low-stakes quizzes, within 1 wk of the content being taught, have been shown to strongly correlate with final exam scores (45–80% predictive value) (32). However, there is evidence that, when the regular quizzes are attached to too high a grade value, the relationship breaks down (20). Our data here are consistent with that observation. It seems that, in both instances of advanced neuroscience, the students used the quiz to boost their grades (with scores of ~70% on the assessment tasks) without real benefit to their learning, measured by the final summative exam.

Remarkably, however, in cardiorespiratory and renal physiology, an improvement in formative assessment performance (~12%) was observed alongside a parallel improvement on the summative exam of nearly 20%. This reinforces the perception that getting student engagement with the flipped learning design was key to achieving better learning outcomes.

Conclusion

Despite evidence that suggests that flipped class andragogy improves students’ learning performance (1, 8) and metacognitive approaches to their learning (39), the evidence that flipped classrooms improve learning performance in physiology education is more ambiguous (2, 16, 19, 35, 38). There is some evidence that the benefits of flipped classrooms may be discipline specific, with greatest benefits seen in the social sciences, and no benefits seen in health and engineering (9). Here we have shown that flipped class andragogy can have major impact on student assessment performance; however, the outcome is dependent on the extent that the students “buy into” the teaching and learning approach. When students treat the class as simply an online class, no benefits are achieved. Student attendance (or presence) is a key factor in achieving success. Effort needs to be spent to design active learning tasks for the classroom that students value and want to attend.

Finally, there is a consistent observation that turning lectures into short chunks of screen capture recordings actually reduces the amount of time spent in didactic teaching. Our data here are consistent with that observation.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

J.A.R. conceived and designed research; J.A.R. performed experiments; J.A.R. analyzed data; J.A.R. and M.S. interpreted results of experiments; J.A.R. prepared figures; J.A.R. drafted manuscript; J.A.R. and M.S. edited and revised manuscript; J.A.R. and M.S. approved final version of manuscript.

REFERENCES

1. Akçayır G, Akçayır M. The flipped classroom: a review of its advantages and challenges. Comput Educ 126: 334–345, 2018. doi:10.1016/j.compedu.2018.07.021.
2. Bethavas V, Bridgman H, Kornhaber R, Cross M. The evidence for ‘flipping out’: a systematic review of the flipped classroom in nursing education. Nurse Educ Today 38: 15–21, 2016. doi:10.1016/j.nedt.2015.12.010.
3. Blaschke LM. Heutagogy and lifelong learning: a review of heutagogical practice and self-determined learning. Int Rev Res Open Distrib Learn 13: 56, 2012. doi:10.19173/irrodl.v13i1.1076.
4. Bleich J. Former Ambassador Jeffrey Bleich Speaks on Trump, Disruptive Technology, and the Role of Education in a Changing Economy. [Online]. [https://theconversation.com/former-ambassador-jeffrey-bleich-speaks-on-trump-disruptive-technology-and-the-role-of-education-in-a-changing-economy-73957] [28 Nov. 2019].
