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A technology-enhanced learning intervention for statistics in higher education using bite-sized video-based learning and precision teaching

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Abstract

Adjustments to life and learning following the COVID-19 pandemic have transformed user acceptance of online learning methods. It is, therefore, imperative to analyse factors relating to user performance and preferences for such interactions. In this study, we combined video-based learning with precision teaching to reinforce previously learnt statistics skills in university students without a mathematical background. We developed a learning design consisting of eight 'bite-sized' online learning episodes. Each episode started with a brief learning video followed by a practice phase and an end-of-episode assessment. The practice phase differed in two groups of participants, matched on statistics attainment pre-intervention. A precision-teaching intervention group (N = 19) completed practice guided by a frequency-based approach aiming at building fluency in statistics. A control group (N = 19) completed self-directed practice for the same amount of time as the intervention group. All participants completed a statistics attainment test and a questionnaire on their attitudes towards statistics pre- and post-intervention, and a review of the learning materials post-intervention. The intervention group achieved, consistently, higher scores in all end-of-episode assessments compared to the control group. Both groups showed significant and comparable improvements in statistics attainment post-intervention. Both groups also reported more positive feelings towards statistics post-intervention, while the review of the learning materials suggested that the video-based learning design was well-received by students. Our results suggest that video-based learning has great potential to support, as a supplementary teaching aid, university students in learning statistics. We discuss future research directions and implications of the study.

Keywords: Bite-sized learning, Statistics, Precision teaching, Computer-based instruction, Video learning, Higher education

Introduction

The coronavirus (COVID-19) pandemic (World Health Organization, 2020) has resulted in important changes in the Higher Education (HE) landscape. Following governmental guidelines, many teaching activities were rapidly transferred to online platforms supporting synchronous (e.g., live lectures) or asynchronous (e.g., pre-recorded lectures) modes of teaching. Initially, many educators and learners experienced feelings of unpreparedness and uneasiness with online formats (Gonzalez et al., 2020; Watermeyer et al., 2021), as well as difficulties due to screen fatigue, distractions from surrounding environments or poor internet connection (Adnan & Anwar, 2020; Xiong et al., 2020). However, this recent period in which the HE sector relied almost exclusively upon online teaching highlighted its flexibility, accessibility, inclusivity, and affordability (Dhawan, 2020; Pokhrel & Chhetri, 2021). There now appears to be an agreement that online learning is more than a short-term remedy for challenges during the pandemic (Rapanta et al., 2020). Online learning offers HE institutions the opportunity to focus on more inclusive student-centred learning approaches and to cultivate collaborative partnerships which are not possible within physical classroom settings (Pokhrel & Chhetri, 2021).

To fully benefit from online learning, it is imperative to monitor learners' performance and preferences during online learning interactions. This enterprise will enable HE institutions to develop engaging online curricula and maximise students' learning outcomes. In this study, we evaluated an online learning design which combined bite-sized video-based learning with precision teaching, in particular frequency-building practice procedures, which aim at helping individual learners to build 'fluency' in the learning material. We utilised this learning design during COVID-19 lockdown (early 2020) as a supplementary teaching aid to reinforce previously-learned statistical skills of HE students without a mathematical background.

Video-based Learning

Video-based learning has been used widely in HE institutions (Pal & Patra, 2020) and under diverse pedagogical strategies, including flipped-classrooms, in which videos are used to introduce the content before face-to-face sessions (Zainuddin & Halili, 2016), or blended-learning approaches, in which videos help students to elaborate or consolidate information presented in face-to-face sessions (Yousef et al., 2014). Video technology enables students to learn outside the physical classrooms and ubiquitously (Hepp et al., 2004). Several meta-analyses have shown that video-based learning enhances students' engagement (Stockwell et al., 2015), learning motivation (Hill & Nelson, 2011), and academic outcomes (Means et al., 2010; Salina et al., 2012). Students also perceive that the possibility of rewinding or revisiting parts of the video is beneficial for their learning (Zhang et al., 2006). More broadly, video-based approaches promote autonomous learning

(Knowles, 1984), as students manage where and when to learn (Fill & Ottewill, 2006). Additionally, videos facilitate knowledge retention through the presentation of information via multiple channels (e.g., graphics: visual, narration: auditory), while they offer information that may not be available in textbooks (Kay, 2012; Turan & Cetintas, 2020).

Brame (2016) suggested three principles for the design of effective educational videos. The first principle is that educational videos should keep cognitive load to a minimum and avoid providing information that does not contribute directly to learning outcomes (Homer et al., 2008). This is important as working memory, which stores information temporarily before it is integrated into our knowledge base in long-term memory, has limited capacity (Sweller, 1988). The second principle is that educational videos should promote student engagement (Brame, 2016). This is crucial as, without the physical presence of an instructor, video-based learning relies upon students' sense of self-discipline and self-motivation to stay focused (Conacher et al., 2004). The third principle for the design of effective educational videos, suggested by Brame (2016) is that videos should foster active learning. This is required to trigger the cognitive activities necessary for knowledge construction and acquisition (Gaudin & Chaliès, 2015; Sablić et al., 2020) and maximise student performance (Freeman et al., 2014).

The segmentation of information into smaller chunks is a useful strategy for ensuring that content is presented in a manageable way and that students maintain their engagement, in line with the first two principles of Brame (2016). "Bite-size" videos enhance learning outcomes (Ibrahim et al., 2012) and are perceived as more engaging and likeable by students compared to the longer ones (Carmichael et al., 2018). A characteristic example comes from Guo and colleagues (2014), who analysed over 6.9 million video streaming sessions and found that videos of less than 6 minutes could reach up to 100% engagement rate. With regard to fostering active learning (the third principle of Brame, 2016), it is recommended that videos should include interactive elements. For example, questions or prompts can be added to help students monitor their own learning, become aware of the key learning targets, and more broadly, develop their metacognitive thinking as self-regulated learners (Gaudin & Chaliès, 2015). Another instructional approach that can promote active learning is precision teaching, which is explored in this study.

Precision Teaching

Precision teaching refers to a detailed ("precision") system to monitor students' learning and evaluate the effectiveness of teaching approaches (Kubina & Yurich, 2012). This system enables teachers to closely monitor the acquisition of targeted skills by students, and students to keep track of their own learning (Sundhu & Kittles, 2016). Within precision teaching, evidence from students' learning performance is used to continuously adjust the teaching approach and optimise learning (Lindsley, 1992).

The central aim of precision teaching is to build fluency in the targeted skills, that is, high levels of accuracy and sufficient speed when performing a target task (Kubina & Morrison, 2000). Fluency is both an indicator of mastery of targeted skills as well as a prerequisite for more advanced skills (Kubina & Morrison, 2000). For example, the ability to decode words accurately and quickly should be mastered before students can construct meaning from a text (Miller & Schwanenflugel, 2008). Furthermore, failure in achieving mastery in basic skills may hinder progress to advanced skills, also referred to as cumulative dysfluency (Binder, 1996; McDowell & Keenan, 2001). Within the precision-teaching framework, fluency is associated with other learning outcomes including retention - performing a task fluently after an interval without training; endurance - carrying out a task fluently for longer duration; stability - not being affected by distractions; and application - combining basic skills to perform a more complex task (Binder, 1996; Kubina & Yurich, 2012).

A widely used approach to support learners in achieving fluency is frequency-building (Kubina & Yurich, 2012). Frequency-building involves training on repeated tasks and within a short period of time, under the aim to increase the rate of correct responses to a predetermined standard (e.g., 60 words typed in a minute; Lokke et al., 2008). Unlike conventional practice sessions, frequency-building uses short practice sprints followed by immediate performance feedback. This is thought to improve performance and fluency in a time-efficient manner (Kubina & Yurich, 2012; Lokke et al., 2008).

In educational settings, frequency-building has been utilised to improve a wide range of skills, including handwriting (Bashore & McLaughlin, 1995), oral reading (Griffin & Murtagh, 2015; Hughes et al., 2007; Lambe et al., 2015), mathematics skills (Chiesa & Robertson, 2000; Hayden & McLaughlin, 2004), and knowledge of academic terminologies (Stockwell & Eshleman, 2010). Frequency-building approaches have also been used in diverse populations, including university graduates (Beverley et al., 2009; Cuzzocrea et al., 2011; Stockwell & Eshleman, 2010) and college students (Olander et al., 1986). For example, Stockwell and Eshleman (2010) demonstrated that frequency-building helped graduate students to develop fluency in behavioural sciences' terminologies and retain this knowledge for 11 weeks even without further practice.

Frequency-building interventions often use so-called flashcards to present information within timed sprints (e.g., Beverley et al., 2009; Hughes et al., 2007; Stockwell & Eshleman, 2010). Flashcards are an easy-to-implement learning tool and can be easily coupled with frequency-building procedures. However, it has also been suggested that flashcards may not be appropriate for college or university settings since they are a relatively rigid form of practice that may not support generalisation of knowledge (Meindl et al., 2013), while they also present methodological limitations related to tracking students learning and engagement (Adams et al., 2018; Beverley et al., 2009). Frequency-building approaches can thus benefit from technology-based approaches, which enhance fidelity in tracking student learning and engagement and systematicity in the presentation of learning tasks (Beverley et al., 2009; Hayes et al., 2018; Killerby, 2005).

Current Study

In this study, we evaluated the learning experiences and outcomes of HE students with an online learning design which combined bite-sized video-based learning with a frequency-building approach under precision teaching. The intervention aimed to reinforce previously learnt statistical knowledge and analysis skills.

We focused on statistics as a target learning domain for two reasons. Firstly, statistics is a challenging topic to teach (Garfield & Ben-Zvi, 2009). Many students perceive statistics to be a boring and difficult subject and present low levels of motivation towards it (Conners et al., 1998). Statistics has also been associated with feelings of anxiety or "statisticophobia" among students (Dillon, 1982; Tishkovskaya & Lancaster, 2012; Verhoeven, 2006). From the educators' perspective, statistics modules are often attended by students with different mathematical abilities and therefore, it is especially difficult to address the needs of both low and high achieving students or design learning materials that would be interesting and relevant to all students (Conners et al., 1998; Wilson, 2013).

A further reason for our choice of statistics was that due to the nature of this subject, there is clear potential to benefit from frequency-building approaches. Building up fluency in prerequisite mathematical skills and abstract thinking are vital for making progress in statistics (Garfield & Ahlgren, 1988). For example, students need to have an adequate understanding of a statistical problem and learn different ways to visualise the data through graphical or table representations before they are able to interpret patterns within the data (Ruz et al., 2018).

The learning design presented in this study was administered during the first lockdown period in the UK (March to July 2020) in the form of a brief online intervention delivered via a user-friendly platform. We explored students' engagement and statistics attainment before, across the duration, and post-intervention, contrasting the performance of two groups, which completed two forms or conditions of learning. The two learning conditions used the same learning material but differed in the way students interacted with it in a practice phase. In particular, an intervention 'frequency-building' group completed practice on the learning material based on the identification of knowledge gaps of individual students with precision teaching and a 'self-directed learning' control group, completed practice on the learning material navigating through it for the same time as the intervention group but in a self-paced way.

We quantitatively assessed students' attitudes toward statistics pre- and post-intervention, and their attitudes towards the learning materials after they completed the intervention.

With these measures, we aimed to address the following research questions: RQ1) Are there any educational benefits of frequency-building on students' engagement and statistics attainment?; RQ2) Are there any benefits of frequency-building on students' attitudes towards statistics after participating in the study?; and RQ3) What are students' views towards the use of bite-sized video-based learning for statistics, and their opinions on the quality of materials used, its potential to complement formal teaching, and its general functionality?

Method

Participants

Thirty-eight adults (33 females, 5 males) with a mean age of 25.29 years (*SD* = 8.83; range 18-52 years old) took part in this study. Participants were recruited through the University's Research Participation System (SONA) and the departmental social media platforms. All participants were university students, with 29 of them registered as undergraduate students and nine as postgraduate students. Ethical approval was sought from the University's Psychology Department Research Ethics Committee.

Materials

For this study, we developed two types of material, instructional and testing. Instructional materials consisted of pre-recorded learning videos. Testing materials consisted of end-of-episode assessments of statistics attainment, a test of statistics attainment, a Survey of Attitudes towards Statistics, and a Review of Learning Materials Questionnaire. The instructional and testing materials are presented below.

Pre-recorded learning videos

Eight brief pre-recorded learning videos (lasting 3-6 minutes each) were developed to cover content from a Research Methods module from the first year of a BSc Psychology course. The learning videos were of two types: 'Concept' and 'Analysis'. The first four learning videos were 'Concept' videos and focused on explaining statistical concepts and terminologies. The following four learning videos were 'Analysis' videos and focused on illustrating and explaining the steps of specific statistical analysis tests using the IBM SPPS Statistical software (IBM Corp., 2017) and the interpretation of the test results.

Two senior academic staff, one male and one female, with experience in teaching Research Methods and Statistics Modules to Psychology students offered guidance in the development of the learning videos. These two staff, who were both native English speakers, also served as presenting tutors in the videos. Each tutor was randomly allocated to half of the 'Concept' and half of the 'Analysis' videos presented in this study. Before recording, the two tutors liaised with the authors to develop short presentations (8 - 17 slides, using Microsoft PowerPoint) and scripts to follow each video.

End-of-episode assessments of statistics attainment

The end-of-episode assessments included 15 multiple-choice questions with four answer choices for each question. These were selected from question banks of two statistics textbooks (Dancey & Reidy, 2011; Field, 2013), and covered the learning content and addressed the learning objectives of the videos. A subject-matter expert (senior lecturer of a university-level course on statistics) provided feedback during the selection process and validated the questions as well as the answer choices.

Tests of statistics attainment

A multiple-choice quiz consisting of 25 questions with four choices for each question was presented as a pre- and post-test assessment of all learning videos. Questions referred to the learning objectives of the videos and were drawn from the bank of questions used in the end-of-episode assessments, ensuring that they were different to the questions of the end-of-episode assessments. Each learning episode contributed at least three questions to the pre- and post-tests to ensure that all content was represented. Participants received no feedback on their performance on these tests.

Survey of Attitudes towards Statistics (36-item version; SATS-36)

Students' anxiety and attitudes towards statistics were measured using the SATS-36 questionnaire (Schau, 2003; Schau et al., 1995). This 36-item scale includes six components: 1) affect – six items (e.g., "I will enjoy taking statistics courses"); 2) cognitive competence – six items (e.g., "I can learn statistics"); 3) value – nine items (e.g., "Statistics skills will make me more employable") 4) difficulty – seven items (e.g., "Statistics formulas are easy to understand"); 5) interest – four items (e.g., "I am interested in being able to communicate statistical information to others"; and 6) effort – four items (e.g., "I plan to complete all of my statistics assignments"). Respondents indicate their level of agreement with a given statement based on a 7-point Likert scale, ranging from 1 (strongly disagree) through 4 (neither disagree nor agree) to 7 (strongly agree). The SATS-36 was found to have high internal consistency ($\alpha = .90$) and have been widely used in previous studies to investigate students' attitudes towards statistics (e.g., Khavenson et al., 2012; Stanisavljevic et al., 2014; Vanhoof et al., 2011).

Review of Learning Materials Questionnaire

The quality of learning videos was evaluated using the Review of Learning Materials questionnaire, developed by the Multimedia Educational Resource for Learning and Online

Teaching (MERLOT, www.merlot.org). The questionnaire consists of three subscales: quality of content – seven items (e.g., "The learning material is clear and concise"), potential effectiveness as a teaching tool – seven items (e.g., "The learning material identifies learning objectives"), and ease of use – five items (e.g., "The learning material is engaging"). Respondents indicate their level of agreement with 19 statements based on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Design

The design of the study is shown in Figure 1. Participants were allocated to two experimental groups, namely a 'frequency-building practice' intervention group and a 'self-directed learning' control group. The two groups were matched at an individual level on their performance on the pre-test assessments and were assessed on their statistics attainment during and post-intervention. Group matching was used for two reasons. Firstly, we needed to control for the effects of participants' prior knowledge in statistics on statistics attainment. Secondly, we needed to control for the amount of time for which participants in the two groups were exposed to the practice procedure (different for the two groups as described below) so that exposure would not be a confounding variable for the performance of the two groups in the post-test assessment.

The individual-based matching of the two groups was implemented as follows. The first 19 participants were assigned to the intervention group. For the following participants, each participant was matched to a unique participant from the intervention group based on a 10% margin criterion. Kolmogorov-Smirnov tests indicated that the assumption of normal distribution was not met for the pre-test score performance of either group (p = .037 for the

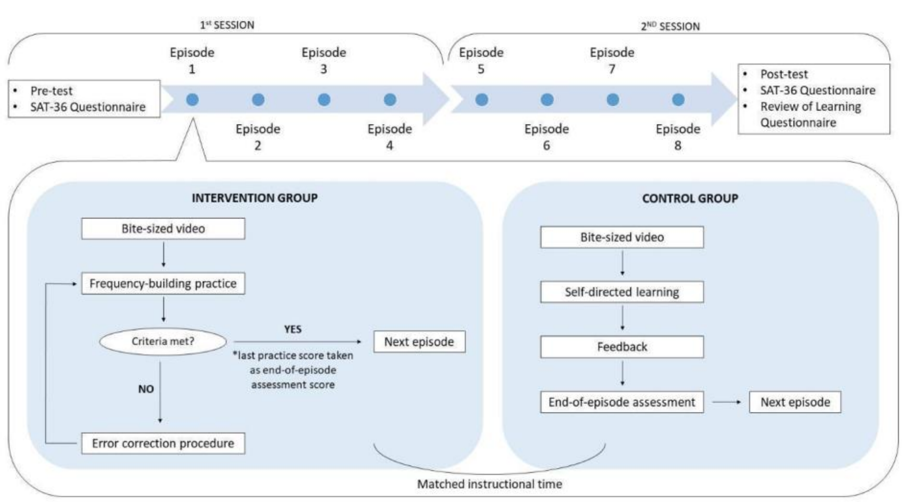


Fig. 1 Design of the study

intervention group, p = .131 for the control group). Based on this result, we used a Mann-Whitney non-parametric test to compare participants' pre-test scores between the two groups. This test showed no between-group difference, U = 175.50, p = .885.

Procedure

Participants completed the study in two sessions. In the first session, participants were administered the pre-test of statistical knowledge, the SATS-36 questionnaire, and four 'Concept' video-based learning episodes. In the second session, participants were administered the subsequent four 'Analysis' video-based learning episodes, the post-test, the SATS-36 post-test version of the questionnaire, and the Review of Learning Materials questionnaire. Both sessions were presented online via Qualtrics (Qualtrics, Provo, UT).

Each learning episode started with participants watching a video, in which the male or the female staff explained a concept or analysis skills in statistics for approximately five minutes. Participants were asked to watch the video until the end, and the next button to proceed with the next part was only presented at the bottom of the page towards the end of the video presentation. Then, participants completed 15 multiple-choice questions which were administered to the two groups as practice. The practice phase allowed participants to familiarise themselves with and consolidate knowledge learnt from the video content. Practice was different in the frequency-building training and the self-directed learning condition. Finally, participants completed an end-of-episode assessment, in which they answered again the 15 multiple-choice questions that were used in the practice phase within a 3-minute timeframe.

The practice phase in the two groups used identical instructional materials and stimuli, however, it was administered in different ways in the two groups as explained in what follows.

Practice in the frequency-building training group

Practice in the intervention group was guided by a high response-rate requirement implemented in iterations of timed sprints and feedback. Participants were told that they would complete a quiz consisting of 15 multiple-choice questions and that they should aim to answer at least 10 questions correctly within a 3-minute time period. When the 3-minute period elapsed, participants received feedback on the number of questions they answered correctly or incorrectly. Then, participants completed an error-correction phase, in which each participant had the opportunity to focus on the questions they had answered incorrectly. Participants were instructed to answer these questions again, without any time limit, and were shown a static relevant part of the video as a reminder activity (see Figure 2i). After the error correction phase, participants answered again the 15 multiple-choice questions presented in a randomised order with the same target criterion (10 correct

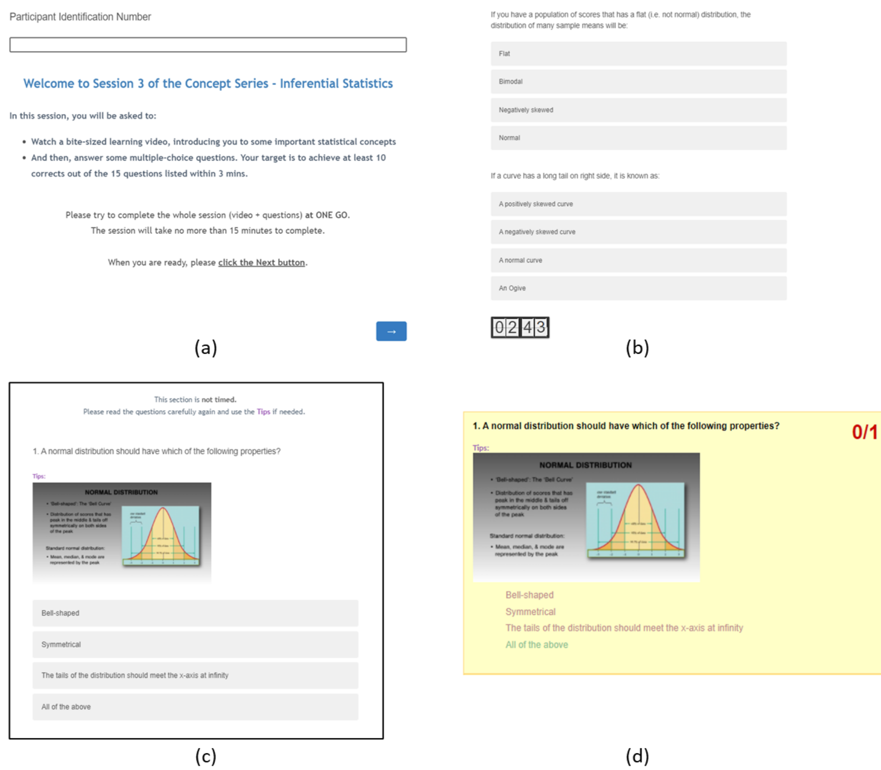
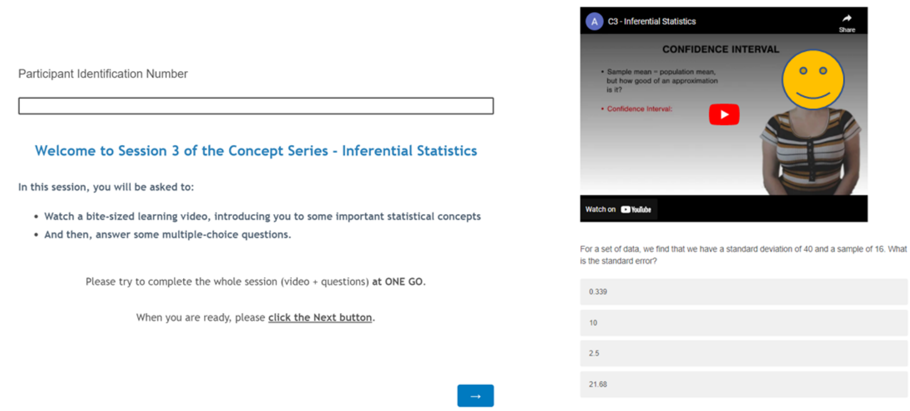


Fig. 2(i) Screenshots of the frequency-building training interface – (a) instruction page; (b) practice assessment page; (c) error correction procedure page; (d) feedback page

answers within 3 minutes). This error-correction phase and assessment cycle were repeated until the target criteria were met. Participants required 1.63 repetitions on average (range 1 – 3) of the whole error-correction and assessment cycle. Once participants achieved the target criteria, they could move to the next episode of video learning.

Practice in the self-directed learning group

In the control group, there were no timed sprints and feedback iterations with a high response-rate requirement. Instead, participants were asked to complete 15 multiple-choice questions without being instructed to meet a target score. Importantly, the total time in which participants were exposed to the practice assessment was identical to their matched counterpart in the frequency-building group. If a participant in the intervention group needed a total of 10 minutes to achieve the target criteria, the matched counterpart in the control group would be exposed to the relevant practice phase for 10 minutes. The next button to proceed was hidden until the time elapsed. The assessment cycle was not repeated in the control group, unlike the intervention group. Instead, participants in the control group were offered the opportunity to refer to the full video content before selecting their answers within that time frame. This was different to the intervention group, who were presented



(a) (b)

Fig. 2(ii) Screenshots of the self-directed learning interface – (a) instruction page; (b) practice assessment page

with the parts of the video that challenged individual participants (see Figure 2ii). When that time elapsed, participants were instructed to complete the end-of-episode assessment.

Measurement and analysis

Quantitative data collected from the end-of-episode assessments and the post-test were used to explore educational benefits of frequency-building practice on students' engagement and statistics attainment, in comparison to self-directed learning during and post-intervention (RQ1). We analysed data from the first session, which focused on statistical concepts, using a 2 x 4 mixed-design ANOVA, with one between-subject factor, Group (frequency-building practice vs. self-directed learning) and one within-subject factor, Episode (Episode 1 to 4). Similarly, we analysed data from the second session, which focused on statistics analysis skills, using a two-factor mixed-design ANOVA, with Group (frequency-building practice vs. self-directed learning) as a between-subject factor and Episode (Episode 5 to 8) as a within-subject factor. The pre- and post-test accuracy scores were examined using a two-way ANOVA, with Group (frequency-building training vs. self-directed learning) serving as the between-subject factor and Time (pre-test vs. post-test) serving as the within-subject factor. Given that the two groups were matched on pre-test performance, group differences would be reflected in a significant interaction between Group and Time factors.

The SATS-36 was used to assess if there were any changes to students' anxiety and attitudes towards statistics following the intervention (RQ2). Participants' responses were scored according to the scoring guidelines of the instrument (available in https://www.evaluationandstatistics.com/) to yield sub-scores across six components: affect, cognitive competence, value, difficulty, interest, and effort. Some items within the components were negatively worded and responses were reversely scored (1 scored as 7, 2 scored as 6, etc.). Scores for each component were calculated by summing the item responses and then dividing it by the number of items within the component. Each component score ranges between 1 to 7, and a higher score indicates more positive attitudes towards statistics. Data were analysed on each component using a two-way 2 x 2 mixed ANOVA, with Group as the between-subject factor and Time as the within-subject factor.

To evaluate students' opinions towards the video-based learning component of this intervention (RQ3), data from the Review of Learning Materials questionnaire (19 items) were analysed per subscale: quality of content, potential effectiveness as a teaching tool, and ease of use. Statistical analysis showed that the internal reliability of these five measures was high (Cronbach's α = .89) and therefore, it is acceptable to say that the questionnaire is an internally valid instrument as it falls within the range of 0.70 to 0.95 (Tavakol & Dennick, 2011).

Results

End-of-episode assessments' accuracy scores

Mean accuracy scores of the intervention and control groups in the end-of-episode assessments are shown in Figure 3.

Concept Learning Episodes: Statistical concepts

A Mauchly's test suggested that the sphericity assumption was not met, $x^2(5) = 0.72$, p = .042, and therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .84). The analysis showed a significant main effect of Group, $F(1, 36) = 21.40$, p <.001, η_p^2 = .373, whereby the frequency-building training intervention group (M = 11.93, SE = 0.35) scored better than the self-directed learning control group (M = 9.67, SE = 0.35) across all four learning episodes. The analysis also showed a significant main effect of Episode, $F(2.53, 91.06) = 11.97$, p <.001, η_p^2 = 0.250. Post-hoc analyses with Bonferroni corrections indicated significant differences in scores between Episode 1 (M = 12.21) and 2 (M = 10.55), Episode 1 and 3 (M = 10.92), and Episode 1 and 4 (M = 9.53). There was also a non-significant trend for an interaction between Group and Episode, $F(2.53, 91.06) = 2.26$, p = .097, η_p^2 = 0.059.

Analysis Skills Learning Episode: Statistical analysis skills

A two-way mixed ANOVA showed that there was a significant main effect of Group, $F(1, 36) = 6.80$, p = .014, η_p^2 = 0.155, suggesting that, similar to the 'Concept' episodes, the overall score was higher in the frequency-building training intervention group (M = 12.54, SE = 0.45) than in the self-directed learning control group (M = 10.90, SE = 0.45). There was also a main effect of Episode, F (3, 108) = 13.77, p <.001,

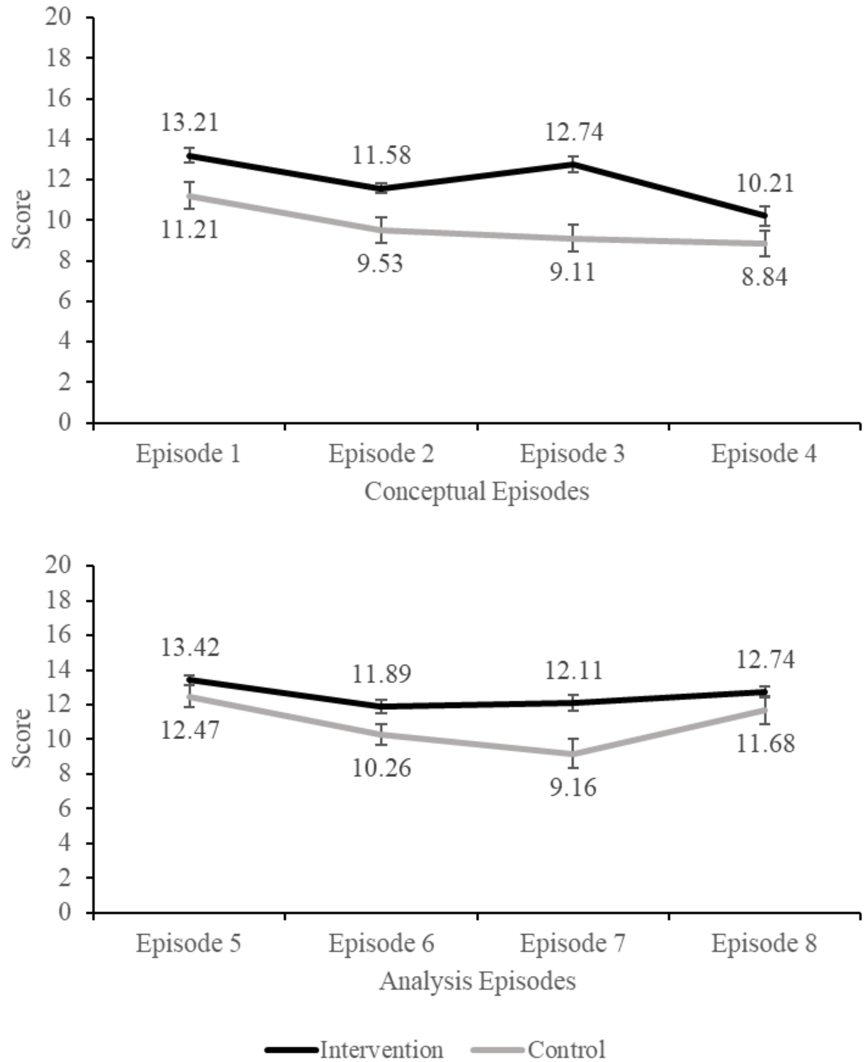


Fig. 3 Mean accuracy scores for both intervention and control groups for the end-of-episode assessments. Scores were calculated out of 15 questions. Error bars represent standard errors of the means

$\eta_p^2 = 0.277$. Post-hoc analyses with Bonferroni corrections showed significant differences in scores between Episode 5 ($M = 12.95$) and 6 ($M = 11.08$), Episode 5 and 7 ($M = 10.64$), Episode 6 and 8 ($M = 12.21$), and Episode 7 and 8. The interaction between Group and Episode was marginally not significant, $F(3, 108) = 2.61$, $p = .055$, $\eta_p^2 = 0.068$.

In a complementary analysis, we compared the differences in scores between higher- and lower-performing participants in the intervention group to gain further insight into the educational benefits of frequency-building across individuals to assess the heterogeneity of the treatment effect. We divided participants who received the intervention into lower-performing and higher-performing categories based on their pre-test scores. Participants

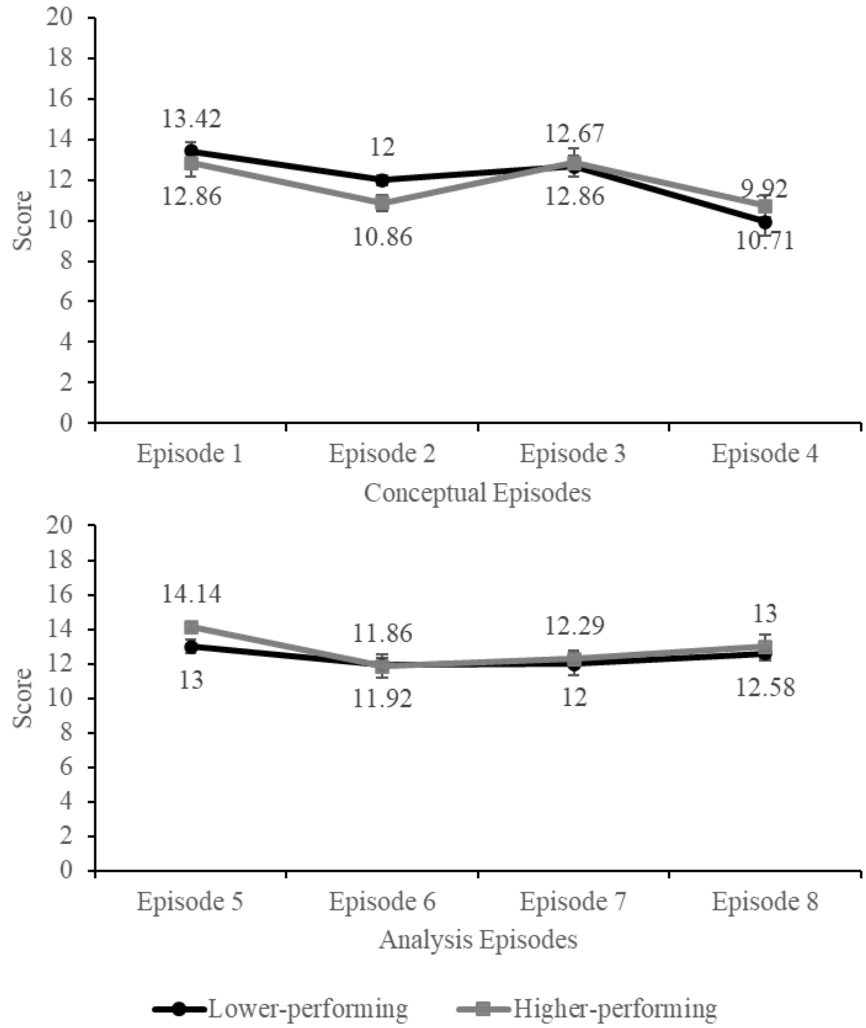


Fig. 4 Mean accuracy scores for lower- and higher-performing participants in the intervention group for the end-of-episode assessments. Scores were calculated out of 15 questions. Error bars represent standard errors of the means

who scored at the 50th percentile and below were placed in the lower-performing group (N = 12), while those who scored above the 50th percentile were placed in the higher-performing group (N = 7). ANOVAs were conducted to identify if there were differences in improvements across these two categories.

Two-way mixed ANOVAs suggested that there was no significant main effect of Performance Level for both the conceptual, $F(1, 17) = 0.19$, $p = .668$, $\eta_p^2 = .011$, and the analysis episodes, $F(1, 17) = 1.29$, $p = .273$, $\eta_p^2 = .070$. However, there were significant main effects of Episode [Conceptual Episodes: $F(3, 51) = 11.05$, $p < .001$, $\eta_p^2 = .394$; Analysis Episodes: $F(3, 51) = 3.92$, $p = .014$, $\eta_p^2 = .187$]. Post-hoc analyses with Bonferroni corrections indicated significant differences in scores between all conceptual episodes, except Episode 1 and 3. For analysis episodes, significant differences were found between Episode 5 and 6 and between Episode 5 and 7 only. The interaction between Performance Level and Episode was non-significant [Conceptual Episodes: $F(3, 51) = 1.20$, $p = .321$, $\eta_p^2 = .066$; Analysis Episodes: $F(3, 51) = 0.44$, $p = .724$, $\eta_p^2 = .025$]. Mean accuracy scores of the higher- and lower-performing participants in the end-of-episode assessments are shown in Figure 4.

In another complementary analysis, we compared differences between groups in the two sessions. To this end, a two-way 2 (Group: Intervention vs. Control) x 2 (Session: First vs. Second) mixed ANOVA was conducted with repeated measures on Session variable. There was a significant main effect of Group, $F(1, 36) = 20.32$, $p < .001$, $\eta p^2 = 0.361$, indicating that the intervention group ($M = 12.24$, $SE = 0.31$) had higher average score compared to the control group ($M = 10.28$, $SE = 0.31$) regardless of the type of learning episodes. There was also a significant main effect of Session, with participants scoring better in the second session ($M = 11.72$, $SE = 0.32$) compared to the first session ($M = 10.80$, $SE = 0.25$), $F(1, 36) = 6.15$, $p = .018$, $\eta p^2 = 0.146$. No significant interaction between the Group and Session was found, $F(1, 36) = 0.70$, $p = .407$, $\eta p^2 = 0.019$, indicating that between-group differences were comparable in the two sessions.

Pre and post-test accuracy scores

Kolmogorov-Smirnov tests indicated that the assumption of normal distribution was not met for both the pre-test ($p = .001$) and the post-test ($p < .001$) score performance. We

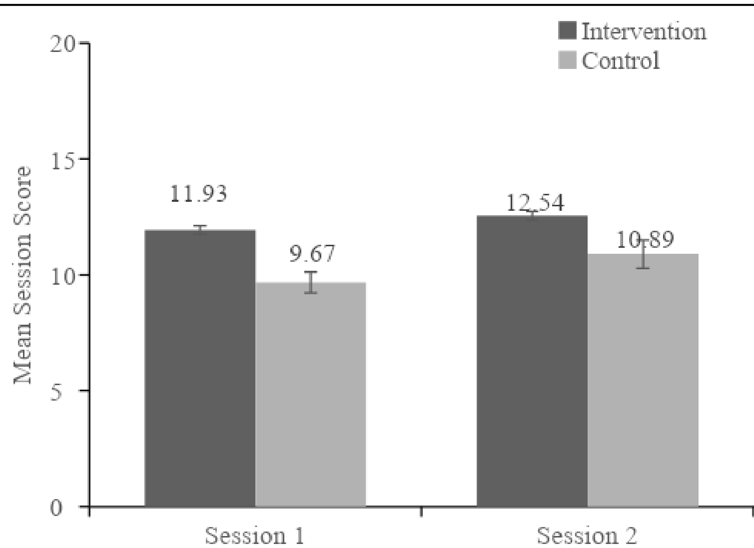


Fig. 5 Mean session scores for both intervention and control groups for the end-of-episode assessments. Scores were calculated out of 15 questions. Error bars represent standard errors of the means

therefore applied a logarithmic transformation to the data [0.5*log((1+pre-test score/25)/(1-pre-test score/25))], to meet the normality assumption and avoid the loss of statistical power due to the use of non-parametric statistics (for a non-parametric analysis of the data, which yielded similar findings, see https://osf.io/2gkqu/?view_only=fee61ba1101f42ffa7b09c6095941534). A two-way 2 (Group: frequency-building practice vs. self-directed learning) x 2 (Time: pre-test vs. post-test) mixed ANOVA was conducted. The results showed that no significant difference in scores was found between the two groups, $F(1, 36) = 0.13$, $p = .726$, $\eta_p^2 = .003$, however, there was marginally significant difference between the pre- and post-test, $F(1, 36) = 4.28$, $p = .046$, $\eta_p^2 = .106$ (see Figure 6). There was no significant interaction between the two factors, $F(1, 36) = 1.367e\text{-}4$, $p = .991$, $\eta_p^2 = 3.797e\text{-}6$.

Pre- and post-test version of the SATS-36 questionnaire

Figure 7 illustrates the means for both frequency-building intervention and self-directed learning control groups on each component of the SATS-36 pre- and post-questionnaire.

Two-way 2 (Group) x 2 (Time) mixed ANOVAs were conducted on the first four components of the questionnaire, namely affect, cognitive competence, value, and difficulty. For the other two components (interest and effort), non-parametric tests were conducted due to the violations of the normality assumption. The ANOVAs' results suggested no significant main effect of Group across the four components: affect [$F(1, 36) = 0.05$, $p = .828$, $\eta_p^2 = .001$], cognitive [$F(1, 36) = 0.03$, $p = .876$, $\eta_p^2 = 6.326e\text{-}4$], value [$F(1, 36) = 0.45$, $p = .505$, $\eta_p^2 = .012$], and difficulty [$F(1, 36) = 0.15$, $p = .705$, $\eta_p^2 = .003$].

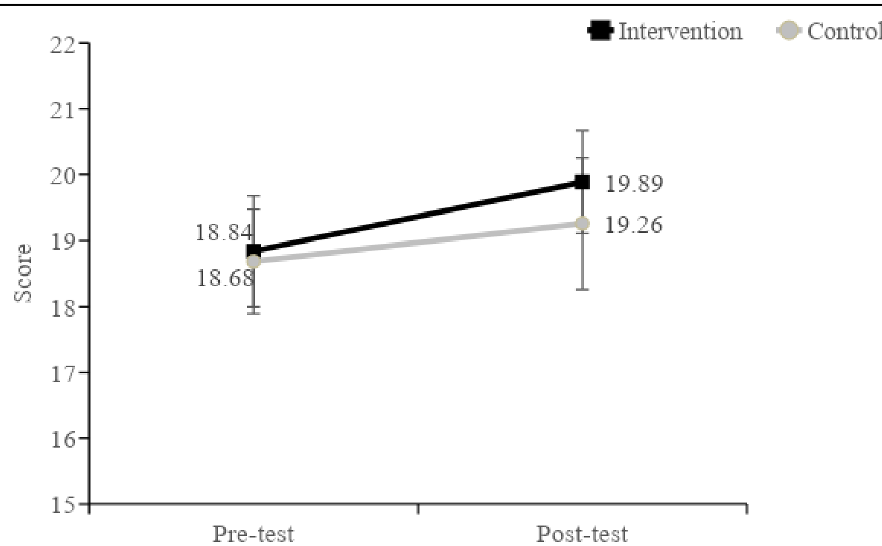


Fig. 6 Mean accuracy scores for both intervention and control groups at pre- and post-test. Scores were calculated out of 25 questions. Error bars represent standard errors of the means

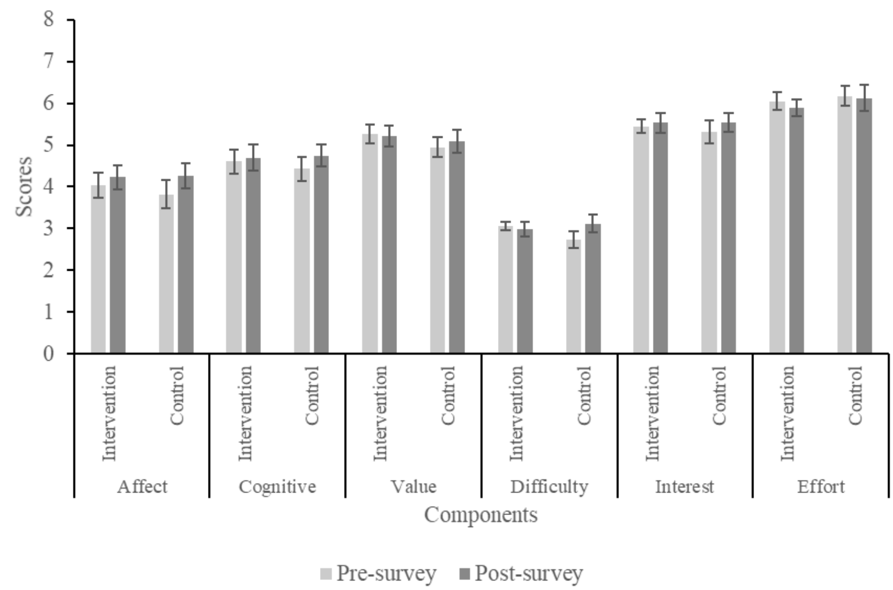


Fig. 7 Average component scores for both intervention and control groups on the SATS-36 pre- and post-survey. Higher bars suggest more positive attitudes. Error bars represent standard errors of the means

Turning to the effects of Time, there was a significant effect on the 'affect' component, indicating an improvement on students' affect (emotion or feeling) towards statistics from pre-test (M = 3.93, SD = 1.36) to post-test (M = 4.25, SD = 1.26), $F(1, 36) = 11.95$, $p = .001$, $\eta_p^2 = .015$. However, the effect of Time was not significant in the other four components, cognitive competence [$F(1, 36) = 3.69$, $p = .063$, $\eta_p^2 = .007$], value [$F(1, 36) = 0.57$, $p = .456$, $\eta_p^2 = 6.346e-4$], and difficulty [$F(1, 36) = 2.89$, $p = .098$, $\eta_p^2 = .012$]. There was a significant interaction between Group and Time on the 'difficulty' component, $F(1, 36) = 5.81$, $p = .021$, $\eta_p^2 = .023$, which arose as participants in the control group uniquely reported that statistics is a difficult subject to a lesser extent post-intervention compared to pre-intervention. Interactions between Group and Time were not significant in the remaining components, affect [$F(1, 36) = 1.89$, $p = .178$, $\eta_p^2 = .002$], cognitive [$F(1, 36) = 1.08$, $p = .305$, $\eta_p^2 = .002$], and value [$F(1, 36) = 1.80$, $p = .189$, $\eta_p^2 = .002$].

With regard to the interest and effort components, Kruskal-Wallis tests suggested that there was no significant difference between groups, interest [$\chi^2(1) = 0.06$, $p = .811$] and effort [$\chi^2(1) = 0.31$, $p = .578$]. Wilcoxon signed-rank tests also demonstrated there was no significant difference between pre- and post-survey scores on the interest ($Z = 154.50$, $p = .171$) and the effort components ($Z = 153.00$, $p = .943$).

Perceptions towards bite-sized video-based learning for statistics

In the Review of Learning Materials Questionnaire, responses were very positive (see Figure 8), with most participants rating "4-somewhat agree" or "5-strongly agree" on a 5-

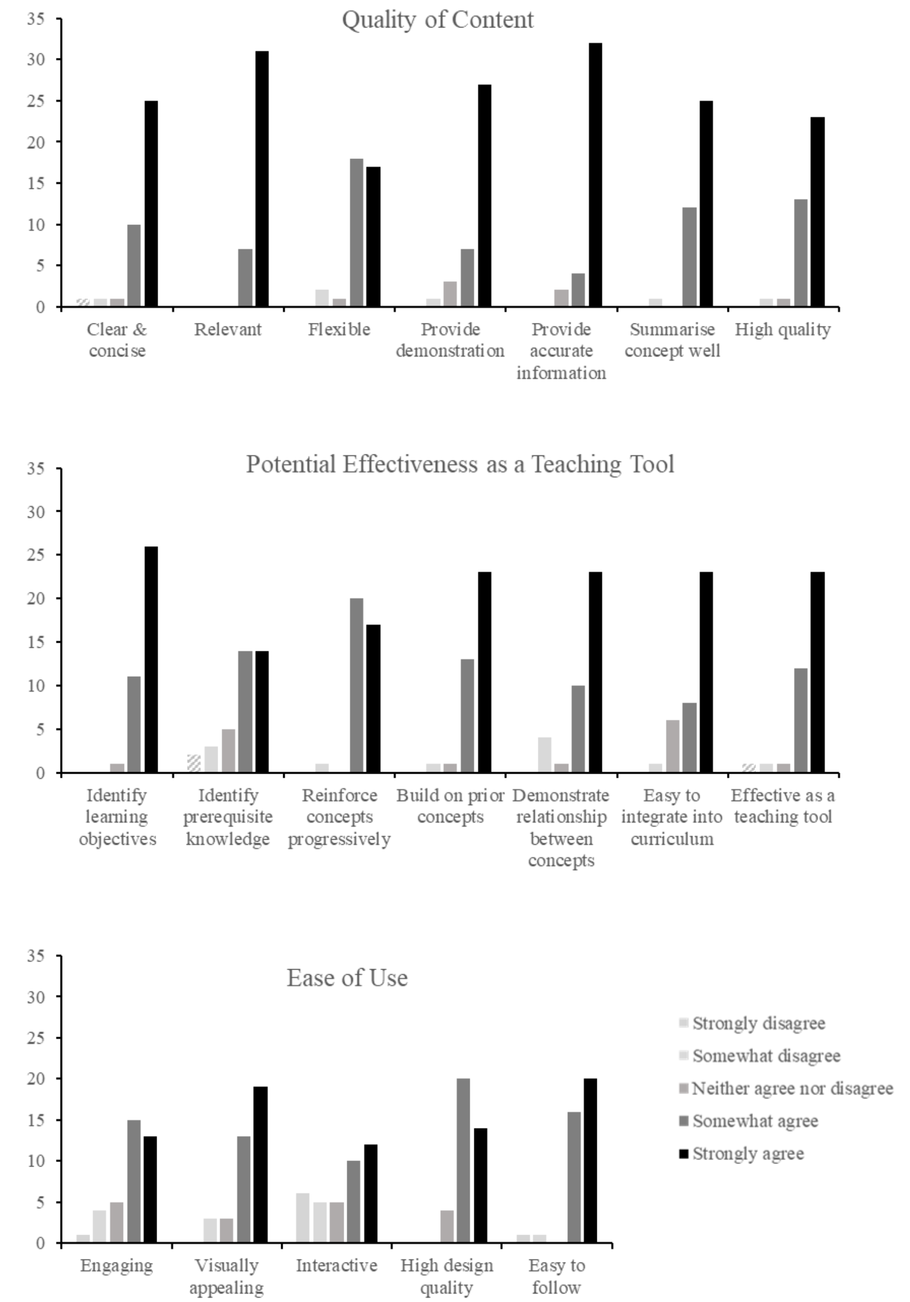


Fig. 8 Frequency of participants' ratings on the Review of Learning Materials Questionnaire. Participants were asked to rate how much they agree with the statements on a scale of 1 to 5, with 1 being strongly disagreed and 5 being strongly agreed

point Likert scale for all 19 items of the questionnaire (M_{rating} = 4.09, SD_{rating} = 0.58). Results of independent t-tests showed that there was no significant difference between the ratings of the intervention and control groups across all three subscales: the quality of content [$t(36) = -0.38$, $p = .709$], potential effectiveness as a teaching tool [$t(36) = -0.39$, $p = .700$], and ease of use [$t(36) = 0.86$, $p = .396$].

Mean rating was reported as 4.35 (*SD* = 0.61) for the first subscale on the quality of content, indicating a high level of satisfaction with the quality of learning materials used in the videos. In particular, all participants agreed that the content presented in these video learning sessions were relevant to their academic work. 97% of participants also agreed that these videos summarised concepts well. Overall, 95% of participants agreed to the statement that these learning videos were of high quality.

For the second subscale, participants gave a mean rating of 4.10 (*SD* = 0.71), meaning that participants generally agreed that these learning videos could be developed into an effective teaching tool. This is evidenced in the last statement of the subscale, with a total of 93% of participants agreeing or strongly agreeing that these video-learning sessions were an effective educational tool. Most participants (97%) also agreed that these videos were helpful in identifying learning objectives, but some stated that it could have explained prerequisite knowledge more explicitly. Nevertheless, 97% of participants stated that these video-based learning sessions reinforced concepts well in a gradual manner.

Mean rating of the last subscale, 'Ease of Use', was reported as 3.74 (*SD* = 0.75). This demonstrates that some participants were indecisive or generally disagreed with some statements that targeted the ways learning materials were presented in the videos. In particular, with regard to the statement that asked participants about the interactive nature of these videos, 29% of participants stated that they disagreed that the learning videos were interactive. 14% of them also disagreed that the videos were to be considered as engaging. However, 90% of participants agreed that these videos had high quality in design and 95% of them also agreed that the videos were easy to follow.

Discussion

The recent experience of almost exclusive reliance of the HE sector on online learning formats during the COVID-19 pandemic highlighted the need for a better understanding of student performance and learning preferences during online learning interactions. In this study, we implemented a bite-sized learning design that combined a video-based learning approach with frequency-building within a precision teaching methodology. This learning design was used to enhance previously learnt statistical skills of university students without a mathematical background.

To evaluate the educational benefits of frequency-building (RQ1), we compared statistical attainment in groups of students who were exposed to identical instructional videos for the same time but under different learning conditions: frequency-building vs self-directed learning. The analyses of the end-of-episode assessments showed that the frequency-building intervention group scored consistently higher than the self-directed learning control group across all eight learning episodes. Furthermore, the effect appeared to be uniform with respect to performance as lower-performing participants presented similar benefits from frequency-building with higher-performing participants. These results were consistent with earlier findings that showed frequency-building facilitates knowledge acquisition and enhances learning performance (Beverley et al., 2009; Stockwell & Eshleman, 2010). Our findings suggest that these benefits also hold for statistics, consistent with Beverley et al. (2009)'s study who showed that a flashcard-supported frequency-building procedure improved statistics performance of undergraduate students. Our study also shows benefits of precision teaching for statistics education within a virtual learning environment. This evidence chimes with evidence from a recent study by Yin and Yuan (2021), who used precision teaching in a blended-learning environment to support a computer technology course in China.

Nevertheless, both groups showed comparable improvements in the post-intervention statistical assessments, suggesting that benefits associated with precision teaching methodologies did not transfer beyond the learning episodes. Although this finding is in contrast with earlier studies that demonstrated the generalisation of skills into novel stimuli (e.g., Beverley et al., 2009, Hughes et al., 2007), it is possible that building fluency in the eight basic statistical topics is not sufficient for skill generalisation. Kubina and Yurich (2012) emphasised that it is important to build fluency in all the basic skills that are prerequisites for more complex skills (rather than a subset of the basic skills). Given that students' difficulties with statistics can be extensive and pervasive across topics, one could argue that this intervention needs to be expanded to more topics to yield noticeable improvements in statistics attainment.

Another possibility for the lack of generalisation is that the benefits of precision teaching are more robust when students who present difficulties in the target learning area. This was the case in Beverley et al. (2009)'s study on statistics, in which participating students had scored at the 50th percentile or below at pre-test. Similarly, Fox and Ghezzi (2003) who used precision teaching for concept formation training, also recruited at-risk students. In our study, we employed a convenience sampling approach. Some participants who took part in our study might have achieved a relatively high average score at pre-test, leaving little room for improvement. Future research could examine the extent to which or ways in which frequency-building can benefit students with low and high abilities.

Turning to changes in the attitudes of students towards statistics (RQ2), our results showed that students in the control groups had less negative feelings about statistics post-intervention. Additionally, there was an improvement in the "affect" scale post-intervention, which was irrespective of learning condition. This is important given the prevalence of negative attitudes and low levels of motivation towards this subject (Conners et al., 1998; Dillon, 1982; Tishkovskaya & Lancaster, 2012; Verhoeven, 2006). Similarly, in their review of the learning materials (RQ3), participants expressed a high level of satisfaction towards the video-based component of this study, irrespective of learning condition. The overall positive judgements of students are consistent with a large body of past research which shows that video-based technology is perceived by students as an effective educational tool (e.g., Hepp et al., 2004; Kay, 2012; Tan & Karaminis, 2020; Turan & Cetintas, 2020). This result also likely reflects students' positive perceptions towards the use of bite-sized videos. By presenting information in smaller chunks, we aimed to maintain participants' engagement with the content and reduce cognitive load requirements (Brame, 2016; Guo et al., 2014).

Educational implications

Our findings are relevant to the current climate in HE, in which institutions embrace fully online or blended-learning formats following the COVID-19 crisis. First, our study shows that technological innovations for statistics education, such as the integration of learning videos in web-based settings are highly acceptable among students. Second, our study demonstrates that technology-enhanced intervention can be developed into an effective educational tool and adopted widely by students in times of crisis to promote active learning outside of the classroom (Tishkovskaya & Lancaster, 2012). Third, our study shows that bite-sized learning episodes are versatile and can be easily accommodated to support ubiquitous learning.

With regard to frequency-building practice, our findings suggest that this type of practice could be valuable for enhancing attainment within individual bite-sized learning sessions. Frequency-building practice and error correction procedures offered individual participants the opportunity to focus on their individual weaknesses before moving on to the next learning episode. This type of practice, which is not typically available in a classroom or lecture, encourages active responses from participants (Barbetta et al., 1993), especially those who are struggling with statistics. This technology-enhanced implementation of precision teaching also addressed limitations of conventional flashcard approaches with the systematic presentation of stimuli and tracking of student engagement (Beverley et al., 2009; Hayes et al., 2018; Killerby, 2005).

There were considerable differences in the magnitude of the intervention effects across learning episodes. The most pronounced differences between both groups were in Episode 3 and Episode 7. The former introduced participants to one of the most challenging conceptual topics in introductory statistics, inference statistics (Kula & Koçer, 2020). The latter focused on the applicable of fundamental statistics concepts in understanding a statistical analysis test. The higher levels of statistics attainment success in these two episodes suggest that the precision teaching framework to focus on fluency of skills could be useful in improving learning of certain complex conceptual materials (Singer-Dudek &

Greer, 2005). As our results were based on evidence from a small number of learning episodes on previously learnt topics, further investigation into how frequency-building procedures impact the learning of both elementary and complex skills is warranted, especially when teaching new knowledge.

Directions for future research and limitations

Our study is not without limitations. In the present design, we matched participants in the intervention group to participants in the control group based on their pre-test scores to determine if any improvement in post-test scores was due to frequency-building practice or mere exposure to instructional materials. Although pairs of participants were of similar statistics abilities at pre-test, we did not account for individual variations in mathematical background (Guàrdia et al., 2006), statistics attitudes and anxiety, and motivation to learn (Chiesi & Prima, 2010). This limitation could be addressed using a within-participant design, whereby the same participants complete learning episodes with and without frequency-building practice.

Another limitation is that as participants were matched on the total time exposure during the practice phase, the number of trials was not controlled for. This implied that the role of repetition of trials during practice was not addressed. As repetition is an important determinant of learning and knowledge retention (Kang, 2016), future frequency-based studies should control for the number of practice items that participants were exposed to in each group.

In line with this account, a more nuanced investigation of learning under precision teaching should also ensure that all groups receive similar instructions. This is important as individuals' learning outcomes measured by the end-of-episode assessments are possibly due to the priming effect of a performance goal. In this study, participants in the intervention group were given the instruction to achieve at least 10 corrects before they can proceed to the next unit; however, there was no such requirement in the control group. As the use of a performance goal could potentially improve one's learning motivation (Chen & Latham, 2014), future research should control the engagement with the learning materials in more detail.

Finally, our study completed all eight learning units across two days. However, there is evidence suggesting that distributing practice across different times of a day benefits the efficiency of frequency-building interventions (Schutte et al., 2015). Research in precision teaching is often conducted over several days, weeks, or even months to allow tracking of learning progress and also measurements of fluency (e.g., Beverley et al., 2009; Stockwell & Eshleman, 2010). As such, it is important to extend the length of this intervention. This will also allow for a better evaluation of fluency, which would also incorporate other measurements, such as retention, endurance, stability, application (Binder, 1996; Kubina & Yurich, 2012).

Conclusion

In sum, our study showed the potential of video-based learning approaches to improve students' engagement and learning performance in statistics, a subject that is often perceived as challenging by students. Frequency-building practice led to enhanced engagement and attainment compared to self-directed practice, although this benefit did not transfer post-intervention. Our video-based learning approach improved in students' attitudes towards statistics and was perceived as an effective learning approach.

Abbreviations
HE: Higher education

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Authors' contributions
Tan, A. J. Y. designed the study, performed data collection, and wrote the original manuscript with support and guidance from all the other authors. Davies, J. and Nicolson, R. I. provided feedback to analyse the data as well as contributed to the review and revision of the final manuscript. Karaminis, T. supervised the work as well as contributed to the planning, discussion of the results and the final manuscript. All authors read and approved the manuscript.

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Availability of data and materials
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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