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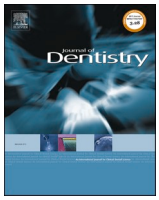

Longitudinal integration of environmental sustainability in the dental curriculum: Assessing changes in student awareness, attitudes and knowledge

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ABSTRACT

Aims: (i) To implement an educational strategy to embed environmental sustainability across all years of an undergraduate dental curriculum and (ii) to evaluate the effectiveness of this strategy through changes in students' awareness, attitudes and knowledge of environmental sustainability in dentistry.
Methods: Four environmental sustainability teaching interventions were delivered across all five years of an undergraduate dentistry programme. A pre-tested survey was administered to students at baseline and post-intervention to evaluate changes in awareness, attitudes and knowledge of environmental sustainability in dentistry (ESD).
Results: A total of 270 matched participants were included in the final comparative analyses, representing a response rate of 69 %. Statistically significant positive changes in awareness of ESD ($p<.001$), attitudes towards ESD ($p=.011$), general pro-environmental attitudes ($p<.001$) and knowledge of ESD ($p<.001$) were observed from baseline to post-intervention. Analysis of the influence of the year of the study demonstrated the effectiveness of the different teaching interventions, with significant differences noted for awareness of ESD ($p<.001$), general pro-environmental attitudes ($p=.022$) and knowledge of ESD ($p=.001$) between year groups from baseline to post-intervention.
Conclusions: This study provides a real-world example of how ES can be longitudinally embedded across the dental curriculum. The effectiveness of this approach has been confirmed through an assessment of the change in awareness of ESD, attitudes towards ESD, the extent to which implementing ESD is easy, general pro-environmental attitudes and knowledge of ESD before and after the curriculum initiative. Significant positive changes were noted for all outcome measures except the extent to which implementing ESD is easy. The most significant changes were noted for awareness of ESD and knowledge of ESD across all years of study.
Clinical Significance: Oral healthcare has a significant environmental impact, the key to all mitigation strategies is by educating the profession at all levels.

1. Introduction

Climate change is a critical global challenge that affects all societies and sectors, including Dentistry [1]. The provision of oral healthcare has a significant environmental footprint [2–4]. The biggest contributors to the environmental impact of oral healthcare are patient and staff travel, procurement and energy use [3]. Transitioning to an oral healthcare model that is more environmentally sustainable oral healthcare will be challenging, and the profession faces numerous barriers, including a lack of professional awareness and a high dependence on single-use plastics [4,5]. These challenges must be directly confronted to meet the ambitious goals of governments and other stakeholders [1,6–9].

Environmental sustainability in dentistry (ESD) has been defined as: "*strategic, holistic and long-term approaches committed to minimising the environmental impact of activities relating to oral healthcare and Oral Health Professional education*" [10]. Providing education related to ESD has been highlighted as a critical approach to making the profession more environmentally sustainable [11], and previous research suggests that

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students, staff, regulators and professional organisations recognise the need to incorporate environmental sustainability (ES) into undergraduate dental education [12–19].

Dental curricula are complex and are usually informed by standards and guidance from national regulators, such as the General Dental Council in the United Kingdom [20–22]. Whilst curricula must meet the regulatory requirements within each country, they must also remain fit for the purpose in the context of a changing profession and society and meet the needs of the local population. ES is an example of an emerging topic that must be incorporated into dental and oral health professional (OHP) education, with national and regional bodies proposing learning outcomes across Europe [18,22]. In this context, the curriculum must be flexible to incorporate ES without deviating from the core aim - to produce high-quality OHPs.

There are limited published models or practical examples to demonstrate how the dental curriculum evolves to include emerging topics. Aside from ES, other social constructs – such as ethics and professionalism - have been incorporated into dental curricula over the past twenty years, but there has been no published guidance on *how* this was achieved [23–26]. Additionally, it is unclear if providing such education results in demonstrable attitude and behavioural change. Existing models of curriculum development can be considered outdated and mainly refer to fundamental changes in curriculum philosophy [27–30]. A structured and pragmatic approach is needed to enable *existing* curricula to develop whilst mitigating disruption to all other processes and stakeholders.

Numerous barriers to embedding ES in the curriculum have been reported, including a lack of curriculum space and resources to guide educators [13,17,31]. Recent research by Dixon et al. [17,32] presents key strategies to embed ES within an *existing* curriculum. This work refers to the need for learners to acquire a baseline 'bolus' of knowledge in the early years of programmes and emphasises the importance of practical reinforcement of ES topics. This research also demonstrated that there may be numerous opportunities within the existing curriculum to *augment* teaching and assessment methods to include ES. This approach avoids developing extensive new teaching and assessment strategies for ES and overcomes the challenge associated with an overloaded curriculum.

It has also been acknowledged that many educators feel they lack the expertise and knowledge to teach ES [13,17,31]. However, for ES to be considered a core part of professional practice, the environmental aspects of dentistry must be taught within all clinical disciplines and curriculum subjects. Additional work by Dixon et al. [32] produced evidence-based and discipline-specific content statements for ESD. These serve as concise statements that can be incorporated into existing teaching events, perhaps as single or multiple slides in a lecture. These statements provide educators with evidence-based messages on ESD and should mitigate concerns regarding misinformation, disinformation and a lack of expertise to teach ES.

While the content and strategies outlined are promising, they need to be implemented and evaluated in a real-life context to determine their effectiveness. While effectiveness can be viewed through numerous lenses, this research will consider whether the strategies are effective at increasing key learner-centred outcomes—awareness, attitudes, and knowledge of ESD.

2. Aims and objectives

2.1. Aim

The aims of this study were: (i) to implement an educational strategy to embed environmental sustainability across all years of an undergraduate dental curriculum and (ii) to evaluate the effectiveness of this strategy through changes in students' awareness, attitudes and knowledge of environmental sustainability in dentistry.

2.2. Objectives

- To assess baseline awareness, attitudes and knowledge of environmental sustainability in dentistry among oral health professional students.
- To deliver a range of learning and teaching events for environmental sustainability in dentistry across the length of the undergraduate dental and OHP curriculum.
- To assess the effectiveness of these learning and teaching events on oral health professional students' awareness, attitudes and knowledge of environmental sustainability in dentistry.

3. Methodology

3.1. Study setting

This study was conducted at the School of Clinical Dentistry, University of Sheffield. Ethical approval was granted by the Research Ethics Committee at the School of Clinical Dentistry, University of Sheffield (application number 061008). All learning and teaching events were conducted within the formally delivered curriculum for the Bachelor of Dental Surgery (BDS) and Diploma in Dental Hygiene and Therapy (DH&DT) programmes. To evaluate the effectiveness of the learning and teaching interventions, pre- and post-intervention assessments of students' awareness, attitudes and knowledge of ESD were measured using an online survey software, Qualtrics (https://www.qualtrics.com).

3.2. Eligibility criteria

All students enrolled on the BDS programme and 1st year of the DH&DT programme were invited to participate in the study. The total cohort size was 390 students. Inclusion criteria for interested participants were:

(i) be enrolled on the undergraduate BDS or diploma in DH&DT programme at the University of Sheffield and
(ii) be able to attend or access all planned teaching sessions for ES within their year of study.

3.3. Interventions

Four learning and teaching methods were termed 'interventions' in the context of the present research. These interventions were delivered to BDS and DH&DT students as part of the formal curriculum from September 2024 to November 2024. All interventions were developed using an evidence-based and research-centred approach, and all strategies and content have been published in peer-reviewed journals [17,18,32]. The interventions were:

- **Intervention 1 - Massive Open Online Course (MOOC) in Sustainability in Dentistry**: An online course developed by the Sustainability in Dentistry task team of the FDI World Dental Federation [33]. This is an open-access resource, and the learning time is approximately three hours. Link: https://www.fdiworlddental.org/sustainability-dentistry
- **Intervention 2 - Standalone lecture for 'Environmental Sustainability in Dentistry'**: A one-hour in-person lecture that aims to

describe the environmental impacts of oral healthcare and outline key mitigation strategies.

- **Intervention 3 – Teaching events with embedded ES content statements:** Embedding ES into existing learning and teaching events across all disciplines through the inclusion of 'content statements' as a single or group of slides [32].
- **Intervention 4 - Clinical case-based discussion centred around ES:** Case-based discussion of clinical scenarios that incorporate elements of ES alongside high-quality patient care. A two-hour session that included multiple cases in restorative dentistry, endodontics, prosthodontics, periodontology and cariology.

Each year of study was exposed to a different mix of interventions to accommodate inclusion within the existing curriculum structure and to ensure the new content was in accordance with their appropriate stage of learning. This approach is beneficial because it represents a real-world example of embedding a topic in an existing curriculum at any given time. Additionally, analysing the change in outcome measures according to year of study will provide insight into the individual and combined effects of the interventions (e.g. by comparing year groups that received single vs multiple interventions).

3.4. Identification and definition of constructs

A survey was identified as a suitable tool to measure the effectiveness of the interventions to promote learning of ESD. Five constructs were identified as key outcome measures: awareness of ESD, attitudes towards ESD, knowledge of ESD, the extent to which implementing ESD is easy and general pro-environmental attitudes. These constructs were selected due to their relevance to current educational frameworks and models for behaviour change [18,22,34,35]. The definition of each construct was informed by previous work, however due to the specificity of the research, these constructs have been explicitly defined for ESD and are outlined below [36–38]:

- *Awareness of ESD*: defined as being conscious and cognisant of the impact of dentistry and oral healthcare on the environment and strategies to mitigate these impacts.
- *Attitudes towards ESD*: this work measures both cognitive and affective attitudes. Cognitive attitudes are defined as the evaluation implied by cognitions about ESD (e.g. the extent to which people believe that ESD is important and worthwhile). Affective attitudes are defined as the evaluation implied by feelings about ESD (e.g. the extent to which people believe that ESD is positive).
- *Knowledge of ESD*: defined as a comprehensive understanding that dental professionals or students possess regarding environmental sustainability practices within dentistry, including familiarity with waste reduction strategies, energy-efficient technologies and methods to minimise the carbon footprint of oral healthcare delivery.
- *The extent to which implementing ESD is easy*: defined as the perception whether performing more environmentally sustainable oral healthcare is considered easy.
- *General Pro-Environmental Attitudes* - defined as an individual's overarching values, beliefs, and predispositions to care for and support the natural environment [36–38].

3.5. Delivery of interventions

Fig. 1 presents an overview of the curriculum interventions with respect to timing and year of study. Participants were invited to complete the survey twice, once before the teaching interventions occurred, to acquire baseline data for the stated measures. The same survey was repeated after the interventions to analyse the effect of the interventions that aimed to increase awareness, knowledge, and attitudes toward ESD. The time lapse between the baseline and post-intervention survey was a minimum of six weeks.

3.6. Instrument development

Two investigators (co-authors JD, HMB) developed the first draft of the questionnaire through an iterative process over several meetings.

	1st BDS	2nd BDS & 1st DH&DT	3rd BDS	4th BDS	5th BDS
Pre-Intervention Survey	September 2024	September 2024	September 2024	September 2024	August 2024
Intervention 1: FDI 'Sustainability in Dentistry' MOOC	October 2024		September 2024		
Intervention 2: Standalone 'ES in Dentistry' lecture		October 2024			
Intervention 3: Embed ES content into existing events	1 event - October 2024	10 events Sepember - November 2024	3 events September - November 2024	7 events September - November 2024	
Intervention 4: Clinical case-based discussion including ES				October 2024	October 2024
Post-Intervention Survey	October 2024	November 2024	November 2024	November 2024	October 2024

Fig. 1. An overview of the planned interventions by year group.

The questionnaire was developed after an extensive literature search to identify existing measures of awareness, knowledge, or attitudes towards ESD. A total of 17 published articles were identified and included in the review. Most sources ($n = 14$) did not report clear methodologies or failed to provide the questionnaire items and, therefore, were excluded. Three articles provided relevant questionnaire items that were developed through a robust methodological approach [19,39,40]. These items were modified to fit the research questions for the present study and used in the first draft of the survey. Other items for awareness and knowledge of ESD were developed *de novo* due to an absence of previous measures. The survey also incorporated previously established and widely adopted measures of general pro-environmental attitudes [37, 41], which allowed comparison against new measures to support their validity.

The first draft of the survey was presented, discussed, and amended in the presence of all researchers. The final draft, before piloting, included 42 items. The survey was programmed on Qualtrics. All questions were made mandatory, and item randomisation was applied to reduce order effects and increase response validity.

3.7. Pre-testing and piloting

A subgroup of BDS and DH&DT students from two different dental schools in the UK tested the survey for face and content validity and to check for possible ceiling effects (i.e. when a large proportion of participants in a study score the highest possible score, meaning that detecting change because of an intervention would be problematic). Ten additional items were added to the questionnaire to gather data regarding clarity of language, ease of use, accessibility, and survey length. A complete analysis of the pilot survey can be accessed at: https://osf.io/b9kgf/?view_only=fa2a4540a24c4902956b6272a5ae139b.

3.8. Final survey development

After analysing the responses to the pilot study, the research team finalised a 41-item survey. The number of items, response options/scales, and example items for each construct are presented in Table 1. The final version of the survey, with information regarding the items included from previous research, is available as an online resource (https://osf.io/b9kgf/?view_only=fa2a4540a24c4902956b6272a5ae139b). No personally identifiable data was collected in the survey. Instead, participants were asked to generate a personal anonymous identifier code to allow matching of responses from both surveys in the follow-up data analysis.

3.9. Recruitment

Participants were invited to participate in the study during face-to-face lectures and by email. The principal investigator (JD) and co-author (NM) delivered in-person lectures at the start of the academic year (August/September 2024) to provide some information regarding the study and invited all students to participate by providing a QR code to complete the pre-intervention survey. One year group (5th BDS) did not have any scheduled lectures and were therefore invited to participate by email. Regardless of their decision to participate in the study, all students were invited to attend the learning and teaching events as these were embedded in the formal curriculum. The approximate total population size was 390 students across all cohorts of the five-year BDS and first year of the DH&DT programmes. This study aimed to recruit at least 50 % of the invited participants.

3.10. Data analysis

The data was analysed using the IBM SPSS Statistics programme (version 29). All constructs were measured on a five-point scale with higher scores reflecting greater awareness of ESD, more positive attitudes towards ESD, more positive general pro-environmental attitudes or greater knowledge of ESD. Descriptive statistics were used to analyse the completion rates and demographic data and means and standard deviations were calculated for all constructs at baseline. A correlation matrix was computed to explore the relationship between all five measured constructs. Correlations, *t*-tests and Multivariate Analyses of Variance (MANOVA) were used as appropriate to explore whether the baseline measures differed according to sample demographics. To enable within-subject analysis, individual responses to both surveys were matched manually using the anonymous participant code. To analyse change in the measures from baseline to post-intervention, a repeated measures MANOVA was conducted. To assess the effectiveness of individual teaching interventions, the MANOVA was modified to include year of study as a between-subjects factor.

4. Results

4.1. Baseline survey data

A total of 351 survey responses were received, representing a response rate of 90 %. Completion rates were favourable, with 333 respondents completing the survey in full, and only 18 (5 %) incomplete submissions were received. A total of 11 submissions were excluded from the analysis as completion ceased after the consent form and

Table 1
Survey sections, number of items, response options/scales and examples.

Survey Section	Number of Items	Response Options/ Scales	Example Item(s)
Demographics	7	A range of multiple choice and free-text options	Age, gender, year of study, experience of dentistry and ESD
Awareness of ESD	4	Five-point Likert scales (Strongly agree - Strongly disagree)	*"I am aware of the environmental impact of dentistry and oral healthcare"*
Attitudes towards ESD	17	Five-point Likert scales (8 items) (Strongly agree - Strongly disagree) Bipolar adjectives on a five-point radio dial (9 items)	*"It is important to me that any dental treatment that I provide does not harm the environment"* *"To me, providing environmentally sustainable dentistry is: "Good" -"Bad"*
General Pro-Environmental Attitudes	8	Five-point Likert scales (Strongly agree - Strongly disagree)	*"Compared to other things in my life, environmental problems are not that important to me"*
Knowledge of ESD	5	Five-answer option single best answer questions	*"The single best strategy to make dentistry more environmentally sustainable is:* *A. Recycle more single-use plastics* *B. Perform minimally invasive procedures* *C. Focus on the prevention of oral diseases* *D. Use eco-friendly materials* *E. Stop using dental amalgam"*

Notes. ESD = Environmental Sustainability in Dentistry. Higher scores reflect greater awareness of ESD, more positive attitudes towards ESD, more positive general pro-environmental attitudes, or greater knowledge of ESD.

Table 2
Responses received by year of study.

Year of Study	Number of Responses	Percentage of Total Sample
1st BDS	70	20.6
2nd BDS	63	18.5
3rd BDS	65	19.1
4th BDS	70	20.6
5th BDS	50	14.7
1st DH&DT	22	6.5
Total	340	100.0

Notes. BDS = Bachelor of Dental Surgery, DH&DT= Dental Hygiene and Therapy Programme.

demographic section. The seven remaining incomplete submissions were included in the analysis where data was available, resulting in a total of 340 respondents.

4.1.1. Demographic data

For gender identity, 218 (64.1 %) identified as female, 114 (33.5 %) identified as male, and 8 (2.4 %) respondents selected the 'prefer not to say' or 'other' options. The gender split within the current sample appears to align with the figures reported locally and in Europe for undergraduate dental programmes [42]. Ages ranged from 18 to 44 (M= 21.6 years; SD = 3.18). Most students (95.5 %) were enrolled on the BDS degree, with 22 (4.5 %) students enrolled on the DH&DT programme. Table 2 presents a breakdown of participants according to each year group of the BDS and DH&DT programmes. There were a similar number of responses for most year groups on the BDS programme, with 5th BDS responses (14.7 %) slightly lower than other year groups (18.5 – 20.6 %). The DH&DT programme has a smaller student cohort, and 22 responses were received from 23 registered students.

4.1.2. Prior experiences in dentistry and environmental sustainability

Less than a quarter of the sample (n = 77; 22.6 %) reported previously working in a dental practice. An exploration of the sample's prior experience of activities related to ESD was varied, with almost half (48 %) of respondents not reporting any previous activities concerning ESD. However, of those that did report some prior experience of activities related to ESD, 91 (26.8 %) respondents reported having attended a formal teaching session associated with ESD, 31 (11.2 %) had attended a talk or a webinar related to ESD, 43 (12.6 %) read a book or a published paper on ESD, and 103 (30.3 %) of respondents had encountered the topic in the media. A further 10 participants (2.9 %) reported completing the FDI World Dental Federation 'Sustainability in Dentistry' MOOC.

4.1.3. Descriptive statistics for all baseline measures

Table 3 provides an overview of the baseline data exploring participants' awareness of ESD, attitudes towards ESD, beliefs about the extent to which implementing ESD is easy, general pro-environmental attitudes and knowledge of ESD using descriptive statistics.

Descriptive statistics indicated a wide range in participants' awareness of ESD, the extent to which implementing ESD is easy, and general pro-environmental attitudes (e.g., scores ranged from 1 to 5). The range for the two attitudinal measures towards ESD suggests that, overall, participants have positive attitudes towards ESD (all scores >2.50). The mean score for the extent to which implementing ESD is easy (M=2.47), awareness of ESD (M=2.99) and general environmental attitudes (M=3.69) were slightly lower than both the attitudes towards ESD measures (Likert scale M=4.23, bipolar adjectives M=4.43). These findings demonstrate that, overall, participants had more positive attitudes towards ESDs than awareness, general pro-environmental attitudes, and consideration of whether implementing ESD is easy. All measures demonstrated good to excellent internal reliability as measured by Cronbach's alpha.

A complete analysis of the knowledge of ESD questions, including the difficulty rating and index for each question, is available as an online resource (https://osf.io/b9kgf/?view_only=fa2a4540a24c4902956b6272a5ae139b). For this construct, the number of correct responses selected for the five single-best answer questions were summed for each respondent. Performance on the knowledge of ESD questions varied among the 333 participants who completed this section, with 4.5 % of respondents selecting no correct answers. Just over a fifth of the sample (21 %) selected one correct answer out of five, 36.3 % scored two out of five, 26.1 % scored three out of five, 10.6 % scored four out of five, and only 1.5 % of participants scored five out of five.

4.1.4. Relationship between baseline constructs

Table 4 presents the bivariate correlations between the baseline variables in this study. General pro-environmental attitudes were positively associated with both measures for attitudes towards ESD (r=0.68 and r=0.47, p's <0.01, for Likert scale and bipolar adjectives, respectively), suggesting that having more positive attitudes towards the environment is associated with more positive attitudes for ESD, specifically. The two measures for attitudes towards ESD (Likert scales and bipolar adjectives) were also positively associated (r=0.53, p<.01), suggesting a moderate-to-strong correlation between the attitudinal measures. However, this correlation was insufficient to consider combining the measures in the subsequent analyses.

Table 4
Correlations between baseline construct measures.

Measures	2.	3.	4.	5.	6.
1. Awareness of ESD	0.18**	0.10	0.05	0.17**	0.09
2. Attitudes towards ESD (Likert scale)		0.53**	0.01	0.68**	0.09
3. Attitudes towards ESD (bipolar adjectives)			−0.04	0.47**	0.08
4. Extent to which implementing ESD is easy				−0.02	−0.07
5. General pro-environmental attitudes					0.13*
6. Knowledge of ESD					1.00

Notes. ESD = Environmental Sustainability in Dentistry. * = correlation is significant at the 0.05 level, ** = correlation is significant at the 0.01 level.

Table 3
Descriptive statistics for awareness of ESD, attitudes towards ESD, extent to which implementing ESD is easy,general pro-environmental attitudes and knowledge of ESD.

Measure	n	Minimum	Maximum	M	SD	α
Awareness of ESD	338	1.00	5.00	2.99	0.76	0.83
Attitudes towards ESD (Likert scale)	338	2.63	5.00	4.23	0.51	0.84
Attitudes towards ESD (bipolar adjectives)	337	2.63	5.00	4.43	0.50	0.78
Extent to which implementing ESD is easy	337	1.00	5.00	2.47	0.88	N/A
General pro-environmental attitudes	339	1.88	5.00	3.69	0.52	0.77
Knowledge of ESD	333	0	5	2.22	1.08	N/A

Notes. n = number; M = mean SD = Standard deviation; α = Cronbach's alpha; ESD = Environmental Sustainability in Dentistry. Higher scores reflect greater awareness of ESD, more positive attitudes towards ESD, more positive general pro-environmental attitudes, or greater knowledge of ESD.

There was a weak positive association between general pro-environmental attitudes and awareness of ESD (r=0.17, p<.01) and specific attitudes to ESD and awareness of ESD (Likert scale, r=0.18, p<.01), suggesting participants with more positive attitudes towards the environment, and ESD specifically, also have greater awareness of ESD. More positive general pro-environmental attitudes were also positively associated with greater knowledge of ESD (r=0.13, p<.05).

4.1.5. Influence of sample demographics on baseline measures

The next stage of the analysis explored differences in sample demographics according to the measures collected at baseline. Such analyses would highlight any differences between groups of participants at baseline and identify possible control variables for the subsequent analyses testing the effects of the intervention.

Correlation analyses demonstrated statistically significant mild positive correlations between age and awareness of ESD (r=0.30, p<0.01), knowledge of ESD (r=0.15, p<0.01), general pro-environmental attitudes (r=0.15, p<0.01) and attitudes to ESD (Likert scale, r=0.11, p<0.05). In general, older participants had greater awareness and knowledge of ESD and had more positive general pro-environmental attitudes and specific attitudes to ESD.

Independent t-tests demonstrated that participants who identified as female (M =3.74, SD=0.49) had more favourable general pro-environmental attitudes than participants who identified as male (M =3.56, SD=0.55; t(329)=−3.07, p=.002, d_{cohen}=0.35). Attitudes towards ESD (measured through bipolar adjectives) were also more positive in participants who identified as female (M =4.49, SD=0.51) than males (M =4.33, SD=0.47; t(328)=−2.70, p=.007, d_{cohen}=0.35). This aligns with previous research findings that demonstrate that, in general, females are more environmentally conscious [43,44]. Females (M =2.30, SD=1.10) also performed better on the knowledge of ESD questions than males (M =2.04, SD=1.00; t(324=−2.10, p=.040, d_{cohen}=0.25). No significant differences were noted between participants identified as male and female with respect to attitudes towards ESD (measured by Likert scales), awareness of ESD, and the extent to which implementing ESD is easy.

An independent t-test was performed to compare responses between the two programmes of study. This demonstrated that DH&DT students (M =3.82, SD=0.62) reported greater awareness of ESD compared to BDS students (M =2.94, SD=0.74; t(336)=−5.38, p<.001, d_{cohen}=1.29). No other statistically significant differences were noted between BDS and DH&DT students for any other constructs.

A MANOVA test was conducted to compare baseline measures across year groups of the BDS programme (see Table 5 for the means and standard deviations for each construct according to BDS year group). Inspection of univariate tests revealed that there were no significant differences between years of study for the measures: attitudes towards ESD, general pro-environmental attitudes and the extent to which implementing ESD is easy (p>.05). However, a significant difference between year of study was observed for awareness of ESD (F(4,308)= 3.17, p=.014, partial n^2=0.04) and knowledge of ESD (F(4,308)=5.86, p<.001, partial n^2=0.07). Post-hoc tests demonstrated that there were significant differences in awareness of ESD between participants in 1st BDS and 3rd BDS. Third-year BDS students (M=3.14, SD=0.75) demonstrated greater awareness of ESD than first-year BDS students (M=2.77, SD=0.74, p=.032). Additionally, significant differences in knowledge were identified between 1st BDS (M=1.80, SD=1.08) and 4th BDS (M=2.49, SD=1.00, p=.001) and 5th BDS (M=2.56, SD=1.05, p=.001).

4.1.6. Influence of previous work experience

An independent t-test demonstrated that participants who had previously worked in a dental clinic (M =3.42, SD=0.70) had significantly greater awareness of ESD compared to participants who had never worked in a dental practice (M =2.87, SD=0.73; t(336)=5.92, p≤.01, d_{cohen}=0.77). No other statistically significant relationships were identified between previous work experience and the measured constructs.

4.2. Post-Intervention survey data

4.2.1. Completion data and participant matching

A total of 363 responses were received for the post-intervention survey. Twenty-five incomplete responses were removed from the data set as they only included responses to the consent form and demographic sections. The final dataset included 338 submissions, of which 321 were fully completed. The pre- and post-intervention survey responses were matched to an individual using the personal anonymous identifier code submitted in the demographics section.

A total of 270 matched participants were confirmed in the final dataset, representing a response rate of 69 %. The remaining responses could not be matched due to differences in the anonymous code submitted. The overall demographics of the final dataset were similar to the baseline survey results, with a mean age of 21.6 years (SD=3.25), and 66.3 % of participants identified as female. Concerning the year of study, a similar split was noticed in the final dataset, with 1st BDS forming 23 % of the sample, 2nd BDS 20.7 %, 3rd BDS 19.6 %, 4th BDS 17.4 %, 5th BDS 13 % and 1st DH&DT representing 6.3 %.

4.3. Comparative analysis: baseline and post-intervention surveys

Analysis of the baseline data revealed that there was a significant difference in gender according to several of the outcome variables. As such, the subsequent analyses were conducted twice, once with and once without controlling for gender. Given that the overall findings remained unchanged, the findings from these analyses are reported below without controlling for gender. Age was also found to be associated with some of the outcome measures in the pre-intervention survey, however, as age is likely to be associated with year of study (one of the between-subject variables in our planned analyses), age was not controlled for in the analyses.

A repeated measures MANOVA was conducted for the six outcome measures (awareness of ESD, attitudes towards ESD – Likert scales, attitudes towards ESD – bipolar adjectives, extent to which implementing ESD is easy, general pro-environmental attitudes and knowledge of ESD) to identify if there was a change in the outcome measures for the whole cohort from baseline to post-intervention.

Follow-up univariate analyses indicated that there were significant differences from pre- to post-intervention for awareness of ESD (F (1,239)=285.54, p<.001, partial n^2=0.54), both measures for attitudes towards ESD (Likert scale F(1,239)=6.54, p=.011, partial n^2=0.03;

Table 5
Baseline data for the constructs according to year of study.

Measures	1st BDS Mean (SD)	2nd BDS Mean (SD)	3rd BDS Mean (SD)	4th BDS Mean (SD)	5th BDS Mean (SD)
Awareness of ESD	2.77 (0.74)	2.85 (0.76)	3.14 (0.75)	2.86 (0.68)	3.14 (0.67)
Attitudes towards ESD (Likert scale)	4.24 (0.5)	4.17 (0.52)	4.24 (0.52)	4.26 (0.52)	4.18 (0.48)
Attitudes towards ESD (bipolar adjectives)	4.42 (0.51)	4.42 (0.54)	4.41 (0.46)	4.46 (0.50)	4.40 (0.50)
Extent to which implementing ESD is easy	2.49 (0.91)	2.55 (0.78)	2.54 (0.79)	2.39 (0.89)	2.31 (0.98)
General pro-environmental attitudes	3.64 (0.52)	3.64 (0.48)	3.70 (0.55)	3.71 (0.51)	3.73 (0.54)
Knowledge of ESD	1.80 (1.08)	2.03 (1.03)	2.27 (1.01)	2.49 (1.00)	2.56 (1.05)

Notes. ESD = Environmental Sustainability in Dentistry. SD = standard deviation.

Table 6
Means, standard errors and p values for the outcome measures across the two timepoints.

Measures	Time	Mean	SE	*p* value	Effect size
Awareness of ESD	1 (Pre)	2.94	0.05	<0.001*	.54
	2 (Post)	3.82	0.04		
Attitudes towards ESD (Likert scale)	1 (Pre)	4.24	0.03	.011*	.03
	2 (Post)	4.32	0.03		
Attitudes towards ESD (bipolar adjectives)	1 (Pre)	4.44	0.03	.001*	.04
	2 (Post)	4.54	0.03		
Extent to which implementing ESD is easy	1 (Pre)	2.46	0.06	.552	.00
	2 (Post)	2.50	0.06		
General pro-environmental attitudes	1 (Pre)	3.70	0.03	<0.001*	.08
	2 (Post)	3.80	0.03		
Knowledge of ESD	1 (Pre)	2.28	0.07	<0.01*	.28
	2 (Post)	3.07	0.08		

Notes. ESD = Environmental Sustainability in Dentistry. SE = standard error. * = statistically significant at $p<.05$. Effect sizes reported as partial eta squared, these can be interpreted as: 0.01 representing a small effect, 0.06 a medium effect and 0.14 a large effect.

bipolar adjectives $F(1,239)=10.73$, $p=.001$, partial $n^2=0.04$), general pro-environmental attitudes ($F(1,239)=19.40$, $p<.001$, partial $n^2=0.08$) and knowledge of ESD ($F(1,239)=93.10$, $p<.001$, partial $n^2=0.28$). There was no difference in the extent to which participants reported that implementing ESD is easy before or after the intervention ($p=.552$). The means and standard deviations for each outcome measure across the two timepoints are presented in Table 6. Inspection of the effect sizes revealed that the changes in awareness of ESD and knowledge of ESD from baseline to post-intervention were considered large, the change in general pro-environmental attitudes was medium and the change in specific attitudes towards ESD was considered small (based on 0.01 = small effect, 0.06 = medium effect and 0.14 = large effect).

Post-hoc tests demonstrated that awareness of ESD improved from baseline ($M=2.94$) to post-intervention ($M=3.82$, $p<.001$). Attitudes towards ESD demonstrated a smaller but statistically significant positive shift from baseline (Likert scales $M=4.24$, bipolar adjectives $M=4.44$) to post-intervention (Likert scales $M=4.32$ $p=.011$, bipolar adjectives $M=4.54$ $p=.001$). General pro-environmental attitudes improved from baseline ($M=3.70$) to post-intervention ($M=3.80$, $p<.001$) and knowledge of ESD also demonstrated a positive change from baseline ($M=2.28$) to post-intervention ($M=3.07$, $p<.001$).

4.3.1. The influence of year group on the extent of change

As different year groups received a different combination of teaching interventions, analysing the influence of the year of study on the extent of change in the outcome measures could reveal the individual or combined effects of the teaching interventions. As such, a five-between (year of study: 1st BDS, 2nd BDS, 3rd BDS, 4th BDS, 5th BDS) by two-within (time point: pre- vs post-intervention) mixed MANOVA was conducted on the six outcome measures.

Univariate analyses demonstrated statistically significant differences by year of study from baseline to post-intervention for the following outcome measures: awareness of ESD $F(4,239)=5.22$, $p<.001$, partial $n^2=0.08$, general pro-environmental attitudes $F(4239)=2.92$, $p=.022$, partial $n^2=0.05$ and knowledge of ESD $F(4,239)=4.67$, $p=.001$, partial $n^2=0.07$. The interaction between year of study across the two timepoints was not significant for attitudes towards ESD (both Likert scales and bipolar adjectives) and the extent to which implementing ESD is easy.

Table 7 presents the means and standard errors for each outcome measure across the year of study and the two timepoints. Statistically significant positive changes in awareness of ESD were observed for all years of study (p's<0.001). For attitudes towards ESD, statistically significant changes were only noted for 1st BDS from baseline (measured through bipolar adjectives $M=4.45$) to post-intervention ($M=4.64$, $p=.002$) and for 2nd BDS from baseline (measured through Likert scales $M=4.23$) to post-intervention ($M=4.38$, $p=.015$). Statistically significant positive changes in general pro-environmental attitudes were observed for 1st BDS ($p<.001$), 2nd BDS ($p=.001$) and 3rd BDS ($p=.031$) from baseline to post-intervention. Knowledge of ESD significantly improved from baseline to post-intervention for all years of study (p's<0.05).

A visual summary of the findings reported above, in the form of line graphs for each construct, are available as an online resource (https://osf.io/b9kgf/?view_only=fa2a4540a24c4902956b6272a5ae139b).

5. Discussion

The overarching aims of this study were (i) to implement an educational strategy to embed environmental sustainability across all years of an undergraduate dental curriculum and (ii) to evaluate the effectiveness of this strategy through change in students' awareness, attitudes and knowledge of environmental sustainability in dentistry. To our knowledge, this is the first empirical investigation to date that has demonstrated and evaluated a strategy to embed ES in the dental curriculum. The present study has demonstrated that embedding ES into the dental curriculum across all years of study is achievable and effective by employing a pragmatic and evidence-based approach. The teaching interventions for ES had a significant positive effect on students' awareness of ESD, attitudes towards ESD, general pro-environmental attitudes and knowledge of ESD. No significant differences were noted regarding students' perception of the extent to which implementing ESD is easy, perhaps reflecting an acknowledgement of the current barriers to delivering environmentally sustainable oral healthcare [4,13,17,31].

It perhaps not surprising that the effect sizes of the interventions were greater for awareness and knowledge of ESD, than that for attitudes towards ESD. Previous research has indicated that changing attitudes is complex and is dependent on the strength of pre-existing values and beliefs [45]. Other research suggests that awareness and knowledge can be considered predictors of subsequent attitudes [43,44]. Positive attitudes are a necessary prerequisite for behaviour change, however, the direct relationship between attitudes and behaviours is complex and not fully understood [35,46–48]. That said, it is encouraging that positive changes were found for both specific and general attitudinal measures, especially as participants reported largely positive attitudes towards the environment generally and towards environmental sustainability in dentistry at baseline (i.e., prior to any intervention).

The strategic plan for this curriculum initiative was developed from numerous educational research projects [17,18,31,32]. A comprehensive approach to situational analysis and needs assessment was performed to establish a need for change [12,17,31,49,50]. Surveys were used to explore the existing context of ES in undergraduate dental and OHP education, and these demonstrated limited evidence of dental schools longitudinally integrating ES in the curriculum [17,31,42,50]. Learning outcomes for the interventions were selected from the Association for Dental Education in Europe (ADEE) consensus document and the recent update to the General Dental Council (GDC) national

Table 7
Means, standard errors and p values for the outcome measures across year of study and two timepoints.

Measures	Year of Study	Time	Mean	SE	*p* value
Awareness of ESD	1st BDS	1 (Pre)	2.74	0.094	<0.001*
		2 (Post)	4.02	0.076	
	2nd BDS	1 (Pre)	2.86	0.10	<0.001*
		2 (Post)	3.82	0.08	
	3rd BDS	1 (Pre)	3.09	0.10	<0.001*
		2 (Post)	3.83	0.08	
	4th BDS	1 (Pre)	2.83	0.11	<0.001*
		2 (Post)	3.64	0.09	
	5th BDS	1 (Pre)	3.16	0.13	<0.001*
		2 (Post)	3.77	0.11	
Attitudes towards ESD (Likert scale)	1st BDS	1 (Pre)	4.28	0.06	.337
		2 (Post)	4.33	0.07	
	2nd BDS	1 (Pre)	4.23	0.07	.015*
		2 (Post)	4.38	0.07	
	3rd BDS	1 (Pre)	4.21	0.07	.441
		2 (Post)	4.26	0.07	
	4th BDS	1 (Pre)	4.31	0.07	.870
		2 (Post)	4.32	0.08	
	5th BDS	1 (Pre)	4.19	0.09	.163
		2 (Post)	4.30	0.09	
Attitudes towards ESD (bipolar adjectives)	1st BDS	1 (Pre)	4.45	0.06	.002*
		2 (Post)	4.64	0.06	
	2nd BDS	1 (Pre)	4.42	0.07	.125
		2 (Post)	4.52	0.06	
	3rd BDS	1 (Pre)	4.39	0.07	.412
		2 (Post)	4.44	0.06	
	4th BDS	1 (Pre)	4.47	0.07	.362
		2 (Post)	4.53	0.07	
	5th BDS	1 (Pre)	4.47	0.09	.210
		2 (Post)	4.57	0.08	
Extent to which implementing ESD is easy	1st BDS	1 (Pre)	2.43	0.11	.515
		2 (Post)	2.51	0.11	
	2nd BDS	1 (Pre)	2.52	0.12	.782
		2 (Post)	2.49	0.12	
	3rd BDS	1 (Pre)	2.59	0.12	.324
		2 (Post)	2.42	0.12	
	4th BDS	1 (Pre)	2.40	0.13	.134
		2 (Post)	2.61	0.13	
	5th BDS	1 (Pre)	2.39	0.16	.715
		2 (Post)	2.45	0.16	
General pro-environmental attitudes	1st BDS	1 (Pre)	3.69	0.06	<0.001*
		2 (Post)	3.90	0.07	
	2nd BDS	1 (Pre)	3.69	0.07	.001*
		2 (Post)	3.85	0.07	
	3rd BDS	1 (Pre)	3.62	0.07	0.031*
		2 (Post)	3.72	0.07	
	4th BDS	1 (Pre)	3.72	0.07	.644
		2 (Post)	3.74	0.08	
	5th BDS	1 (Pre)	3.79	0.09	.901
		2 (Post)	3.80	0.09	
Knowledge of ESD	1st BDS	1 (Pre)	1.97	0.14	.006*
		2 (Post)	2.41	0.16	
	2nd BDS	1 (Pre)	2.04	0.14	<0.001*
		2 (Post)	3.44	0.17	
	3rd BDS	1 (Pre)	2.21	0.15	<0.001*
		2 (Post)	2.96	0.17	
	4th BDS	1 (Pre)	2.57	0.16	<0.001*
		2 (Post)	3.22	0.18	
	5th BDS	1 (Pre)	2.61	0.19	.002*
		2 (Post)	3.32	0.22	

Notes. ESD = Environmental Sustainability in Dentistry. SE = standard error. * = statistically significant as $p<.05$. The p-values demonstrate where there was significant change in the outcome measures from baseline to post-intervention by year of study.

framework in the UK [18,22]. From this, appropriate teaching and assessment methods were chosen to ensure constructive alignment [51]. The selected approaches were informed by the themes that emerged from exploratory focus groups with local educators and students [32]. These established the need to teach ES across all disciplines, the importance of baseline knowledge transmission with practical reinforcement of the topic and provided valuable proposals to incorporate ES into *existing* teaching and assessment events. Educators across all curriculum subjects were provided evidence-based and subject-specific content to augment their teaching events [32].

The four interventions were integrated across all year groups according to the opportunities presented in the existing curriculum. This demonstrates an example of an approach to embedding ES within a local curriculum structure where there is limited flexibility or space to add

numerous new events. In this study, the FDI 'Sustainability in Dentistry' MOOC was delivered to 1st and 3rd BDS students to provide core baseline knowledge of ES in dentistry and oral healthcare [33]. It was necessary to select two different year groups for this intervention in the first cycle, as students had not experienced any ESD teaching previously in the curriculum. In the future, the MOOC will be delivered to one year group only to avoid repetition. A standalone lecture was delivered in a face-to-face format for 2nd BDS and 1st DH&DT, which provided information regarding climate change, the contribution of dentistry to the climate crisis and proposed strategies to deliver more environmentally sustainable oral healthcare. The timing of this lecture coincided with the pre-clinical skills practical course, which also included sustainability teaching through flipped classroom learning and in-person practical teaching. The evidence-based content statements were embedded into 21 *pre-existing* events as a single or group of slides across four years of study. These events included lectures and flipped learning from 10 different curriculum subjects, including dental public health, cariology, periodontology, paediatric dentistry, oral pathology and professionalism and ethics. The case-based discussion provided an opportunity for 4th and 5th BDS students to review patient care planning and develop an understanding of how structured and smart care delivery can mitigate the environmental impacts. The environmental impact of various treatment modalities was also reviewed.

The design of the present research provided an opportunity to consider how the year of study influenced the extent to which a change in awareness, attitudes and knowledge was observed. This provided insight into the impact of individual or a mix of interventions. All years of study demonstrated a significant improvement in awareness of ESD, suggesting all four interventions were effective for this outcome measure. However, 1st BDS, who completed the MOOC and received one lecture on professionalism and ethics, which included ES content, demonstrated the greatest increase in awareness. Potentially, this occurred due to a lack of previous dental experience and the steep learning curve for this new student cohort, who had to gain an understanding of dentistry and ES through the MOOC. Additionally, there was more scope for improvement due to the lower baseline score reported in this year group for awareness of ESD.

For attitudes towards ESD, a smaller change was noted, and the pairwise comparison for each year group revealed that only 1st BDS and 2nd BDS presented significant differences in this outcome measure from baseline to post-intervention. As 2nd BDS received more teaching interventions compared to other year groups (one dedicated ES lecture and ten events with ES content statements) and were exposed to practical learning of ES in a clinical simulation setting, it can be hypothesised that cumulative learning and practical reinforcement is needed to promote greater changes in people's attitudes. Interestingly, the 4th and 5th BDS were the only year groups that did not demonstrate a significant change in general pro-environmental attitudes. These year groups did not receive any baseline knowledge teaching for ES and only experienced practical application of the topic in a case-based discussion. This finding demonstrates the importance of baseline knowledge transmission in the early years of programmes, as discussed in previous research by Dixon et al. [32]. With respect to knowledge of ESD, positive changes were noted for all years of study, demonstrating the effectiveness of all teaching interventions in improving knowledge. The greatest increase in knowledge of ESD was observed in 2nd BDS, again demonstrating the impact of more teaching hours and the need for practical reinforcement [32]. The smallest increase in knowledge of ESD was noted for 1st BDS, perhaps reflecting this cohort's lack of academic and clinical experience and potentially the limitations of using an online resource exclusively for education in this area.

The results of this study are very promising and provide evidence that strategically planned, and contextually correct learning and teaching, can improve awareness and knowledge and promote more positive attitudes. This is particularly important in the current dental educational context, where socio-cultural topics are embedded in the curriculum, with the anticipation that education will result in positive attitudinal and behavioural change in graduating OHPs. Additionally, as this curriculum initiative interweaves ES content across all years of the undergraduate dental programme, it is anticipated that the cumulative learning from all interventions will result in a greater change in awareness, attitudes and knowledge of ESD at the end of the five-year cycle than what has been observed in this study that assessed change within a single academic year.

The review of the literature suggests that this is the first published example of planning, implementing and evaluating the longitudinal integration of ES in a formally delivered health professional curriculum. Previous examples of teaching ES have been limited to smaller-scale interventions typically applied opportunistically at one point in the curriculum [52–56]. These early interventions appeared to be led by educators with a particular interest in ES and served as an excellent starting point to raise awareness. Additionally, these studies have demonstrated that single events may improve knowledge of ESD but are unlikely to result in meaningful changes to awareness and attitudes towards ESD.

The main limitation of this work relates to the difficulties encountered when matching participants' pre- and post-intervention responses due to variations in the personal anonymous identifier code reported. This resulted in a loss of participants in the final comparative analyses. For future work, consideration should be made to emphasise the importance of accurate submission of the code during participant recruitment and also modifying the code and the associated instructions. Additionally, whilst this work demonstrated significant improvements in awareness, attitudes and knowledge of ESD, the researchers acknowledge there are challenges in translating this into actual behavioural change. Actual behaviour in practice could not be assessed in this study, but it could be assessed in future work.

5.1. Opportunities for future research

This study has demonstrated the positive impact of ES-specific teaching interventions on awareness, specific attitudes, general attitudes and knowledge of ESD within a single academic year. As this approach has embedded ES across all years of the undergraduate dental programme, a long-term review of the effectiveness of these interventions across the length of the curriculum would be of interest, with a particular focus on the magnitude of change for specific attitudes towards ESD and general pro-environmental attitudes. Additionally, exploring the relationship of these positive changes in attitudes to demonstrable behaviour would be of interest, as the translation of knowledge and attitudes to behaviour is not linear [35,46]. Finally, this research-centred approach to curriculum development could be applied to other constructs such as social accountability, resilience and interprofessional education.

6. Conclusion

This study provides a real-world example of how ES can be longitudinally embedded in the dental curriculum with minimal disruption to the existing educational philosophies and goals. The most significant changes in outcome measures were noted for awareness of ESD and knowledge of ESD across all years of study. General pro-environmental attitudes and specific attitudes towards ESD demonstrated a lower gradient of change, perhaps reflecting the need to review the effectiveness of the cumulative learning events on these outcome measures in the longer term across the whole curriculum. All four teaching interventions appeared effective, although increased exposure to ES teaching and practical learning seemed to be significant positive indicators of change. The need for baseline ES teaching in the early years of programmes was also observed.

CRediT authorship contribution statement

Jonathan Dixon: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Harriet M. Baird:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **James Field:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization. **Nicolas Martin:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

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Research data

The survey items and raw data from both the baseline and post-intervention survey can be accessed freely at https://osf.io/b9kgf/?view_only=fa2a4540a24c4902956b6272a5ae139b, under the terms of the Creative Commons Attribution (CC BY-NC 4.0) licence.

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