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Towards a model of plant awareness in education: a literature review and framework proposal

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ABSTRACT

The inattention to plants, known as 'plant blindness' or 'plant awareness disparity', is an established concern amongst biologists and educational practitioners alike. Many studies have called for a teaching and learning reform in botany, but there has been no thorough or critical examination of the pedagogic literature to date, an issue which this narrative review of studies (1998–2022) seeks to address. We use a framework based on theories of perceptual attention, interest, and attitude formation to derive novel insights about increasing plant awareness in education. Data were extracted using a suite of search terms, characterised using key words and subjected to a thematic content analysis, with 113 studies shortlisted for review. The dominant teaching and learning approaches were identification keys, laboratory investigations and discussion-based approaches. Educational interventions were found to increase plant awareness by providing memorable and meaningful first-hand encounters with plants and generating positive affect. We present a theoretical model based on these findings and discuss the implications for biology education.

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Plant awareness; biology education; review; botany

Introduction

Plants are essential for the survival of life on Earth. Plant diversity plays a central role in the functioning of terrestrial ecosystems, which in turn drive the provisioning services on which humans depend (Quijas et al., 2010). Despite our dependence on plants, there is a widespread tendency in urban societies to ignore plants or underappreciate their importance, a phenomenon known as 'plant blindness' (Wandersee & Schussler, 2001) or 'plant awareness disparity' (PAD) (Parsley, 2020).

There is an ongoing debate about the relative contribution of innate (genetic) and cultural factors to plant awareness, but the neglect of plants in education is undisputed and well-documented (Stagg & Dillon, 2022). Multiple studies have shown a bias towards animals as compared to plants in school curricula and textbooks, and poor pedagogic

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content knowledge in pre-service and qualified teachers. Learners exhibit low interest and negative attitudes towards plants, or a preference for animals (for a review, see Stagg & Dillon, 2022). In the UK, low coverage of plant topics across undergraduate biology programmes has been reported (Stroud et al., 2022), and a growing skills gap in science and land-based professions (Langdale, 2021).

Numerous studies have called for improvements in teaching and learning about plants but there has been no systematic assessment of the experimental (intervention-based) pedagogical literature to date. This study explores the literature to identify which pedagogic practices are used for plants and aims to explain the underpinning theoretical basis for why certain pedagogical practices are effective in increasing plant awareness. This approach will strengthen our understanding of the principles that we should follow in the design of future interventions or in a reform of professional teaching practice.

Constructs relating to plant awareness

In this study, we focus on plant awareness, the acquisition of positive traits towards plants because, like Pany et al. (2022), we believe a focus on the positive qualities we aim to promote is more valuable pedagogically than a focus on deficits. A construct is defined as a coherent suite of interacting affective, cognitive, and behavioural variables (Fried, 2017) and 'plant awareness' was first described as a construct by Pany et al. Pany et al. proposed four variables: perceptual attention, categorisation of plants as living organisms, knowledge and attitudes. Their work builds on Parsley et al. (2022) PAD Index, based on attention, attitude, knowledge and relative interest (plants compared to animals). Research instruments designed to assess plant blindness include Amprazis et al. (2021), Batke, Dallimore and Bostock (2020) and Fančovičová and Prokop (2010), using similar variables. These studies provide first steps to conceptualising and assessing plant awareness/PAD but are far from perfect and fall short of effective practice recommendations for construct definition, design and validation (Lambert & Newman, 2023). Common faults included a failure to use the established psychological definitions for component variables and disparities between variable definitions and measurement scales or items. Many scales were over-reliant on self-reported items, statements to which respondents indicate their level of agreement using a rating scale and are prone to response bias (e.g. Valencia, 2020). Some studies relied on low numbers of response items or failed to assess the internal consistency between scale items. Few studies considered how plant awareness/PAD is related to other relevant constructs, for example nature connectedness. This research field will benefit from further attention and the development of more coherent concepts and instruments.

Theoretical framework

This framework aims to explain the theoretical underpinnings for the variables in the plant awareness/PAD constructs and their interactions. We will use this framework to examine the experimental literature about plant pedagogy, to develop interpretations and insights for increasing plant awareness in education and offer a basis for how educational interventions might be designed.

Perceptual attention

Perceptual attention describes the way in which mental resources focus on certain stimuli in the environment, at the expense of others (APA, 2022), which, in plant awareness, is the extent to which plants are noticed in the physical environment compared to other elements (usually animals).

According to Gibson's (1966) and Gregory's (1970) theories of visual perception, what we allocate attention to is determined by the intrinsic qualities of a visual stimulus, for example its colour and structural complexity, as well our existing mental representations about the stimulus. The strength of our mental representations depends on how meaningful and memorable our previous experience with the stimulus was, for example whether there was relevant linguistic information accompanying it (Collins & Curby, 2013), or whether emotional arousal occurred, including empathy (Kanske et al., 2013). Roskos-Ewoldsen and Fazio (1992) also showed that the objects that attracted most attention within the visual field were those that have strong, accessible evaluations (attitudes) associated with them.

Prior knowledge also influences perceptual attention, not just by rendering a stimulus more meaningful but also by enabling us to make sense of the stimulus and its component parts, and committing it to memory (Kim & Rehder, 2011). Retrieval practice (any strategy that induces us to deliberately recall stimuli and information associated with them), implemented effectively, strengthens mental representations and is an important strategy in teaching and learning (Roediger et al., 2006). The importance of these factors could explain why plant blindness is not observed in traditional, resource-dependent societies, where there are regular interactions with plants with meaning and relevance to people's daily lives (Stagg & Dillon, 2022).

According to Lavie's (1995) Perceptual Load Theory, the perceptual attention we allocate to stimuli in the environment is also determined by how much attention must be allocated to processing task-relevant stimuli. If there is a high perceptual load, we are more likely to ignore, or fail to see, some of the stimuli in the visual field.

Interest

Interest is a variable integrating positive affect, motivation, and cognition, which arises from a positive emotional response to a task, leading to sustained attention and an increase in learning (Ainley, 2006). The initial activation of interest, triggered situational interest, relies heavily on external conditions, namely qualities of the stimulus, for example novelty, complexity and how meaningful or comprehensible it is for the individual (Renninger & Hidi, 2022). Initial interest may progress to maintained situational interest and, over time, to durable personal interest, a process that is strongly moderated by internal processes. Krapp (2007) proposed that these internal processes are based on a "dual regulation system", comprising cognitive-rational and emotional control mechanisms, in their person-object-theory of interest. The cognitive mechanisms are influenced by existing knowledge about the object or content. Interest development will only occur if the focal object or content are perceived positively in cognitive-rational evaluations and positive emotions are experienced. This leads to the internal desire to apply oneself to learning, known as intrinsic motivation, the reverse of motivation driven by external factors like success or financial reward.

According to Ryan and Deci's (2000) self-determination theory, humans possess a suite of innate psychological needs, distinct from biological needs but equally important for survival. The authors proposed that the most important psychological needs for intrinsic motivation to develop are competence, autonomy and relatedness. Competence describes the desire to fulfil the requirements associated with a task and feel like one's abilities are being utilised and extended by the task. Autonomy explains the desire to feel like one is acting with a sense of choice when undertaking a task, without being overly influenced by uncomfortable external or internal pressures. Relatedness refers to the desire to feel accepted and supported by other individuals engaging in the task. These three needs are inter-related, for example competence is experienced when there is a sense of autonomy in tackling the task. Exploring learners' need-related experiences provide valuable insights into whether learning could lead to durable interest development.

Attitude

Attitude is the stable and enduring summary evaluation of a phenomenon that arises from a person's beliefs, emotions, and past behaviours (Maio et al., 2018). Attitude encompasses the perceived importance, appreciation, and preference for a phenomenon, which are commonly studied traits of plant awareness. Attitudes are closely linked to a person's beliefs, views, or judgements, which may or may not be based on fact or knowledge (Newhouse, 1991). Two well-documented beliefs about plants are shown to contribute to negative attitudes. The first is that plants are 'less alive' than animals because they lack obvious movement or active behaviours, which Yorek et al. (2009) defined as the 'life concept'. Secondly, an underestimation of the importance of plants for human survival or the biosphere (e.g. Amprazis et al., 2021).

Knowledge used to be considered a key factor in shaping environmental attitudes, but studies since have shown that knowledge alone exerts a weak influence on attitudes, captured by the 'information deficit' model (Kollmuss & Agyeman, 2002). However, Kubiatko et al. (2021) identified a positive association between young people's favourable attitudes, knowledge and interest towards plants.

Attitudes are more strongly influenced by first-hand experience of a phenomenon than indirect experience, and reinforced by repeat exposures (Newhouse, 1991). The impact of experience on attitudes is affected by the interaction between experience and existing beliefs. If a person believes a snake is slimy, for example, then first-hand experience could have a positive impact on attitudes, whereas if a person believes a spider is scary due to its rapid movement and long legs, experience could strengthen the negative attitudes.

Like attention and interest, emotional arousal also has a strong influence on attitudes, particularly empathy (Kollmuss & Agyeman, 2002). Developing an emotional connection with nature has long been shown to increase positive attitudes to its conservation, from Chawla's (1998) work on 'environmental sensitivity', to Lumber et al.'s. (2017) work on 'nature connectedness'. However, it is important to highlight that intervention-based experiences can only exert a limited influence on attitudes since they are also modulated by the life experiences and influences arising from social norms and cultural practices (Newhouse, 1991).

Knowledge

Processes like information recall, conceptual understanding and skills development, as well as existing conceptions and beliefs and social interactions, play an important role in knowledge construction (Nantawanit et al., 2012). As discussed above, knowledge can have positive influences on perceptual attention and interest development and may also influence the formation of attitudes.

Focus for this enquiry

This study examines the pedagogic practices used in the literature, which facets of plant awareness they are suggested to address, and the impact, if any, they are shown to have. The results of this study will enable us to articulate (and explain the underpinning theoretical basis for) pedagogical design that could increase plant awareness. The research questions: (1) What is the relative coverage of different topics of plant biology in educational research and which pedagogic approaches are used? (2) Which elements of plant awareness are addressed in the pedagogic literature and how? (3) How does this body of literature advance our understanding of pedagogic practice for increasing plant awareness, based on theories of perceptual attention, interest, attitude and learning?

Methods

The literature for this study was extracted as part of a previous review about the characteristics of human-plant relations in different societies (Stagg & Dillon, 2022) but subjected to a novel screening process and synthesis for this inquiry. The original literature was extracted from 1 May 1998–4 April 2020 but extended to 31 December 2022, using the same procedure. An overview is provided in Figure 1. The search strategies and screening were based on systematic review methods, with the aim of being thorough and objective in scope. A narrative review approach was used to produce an

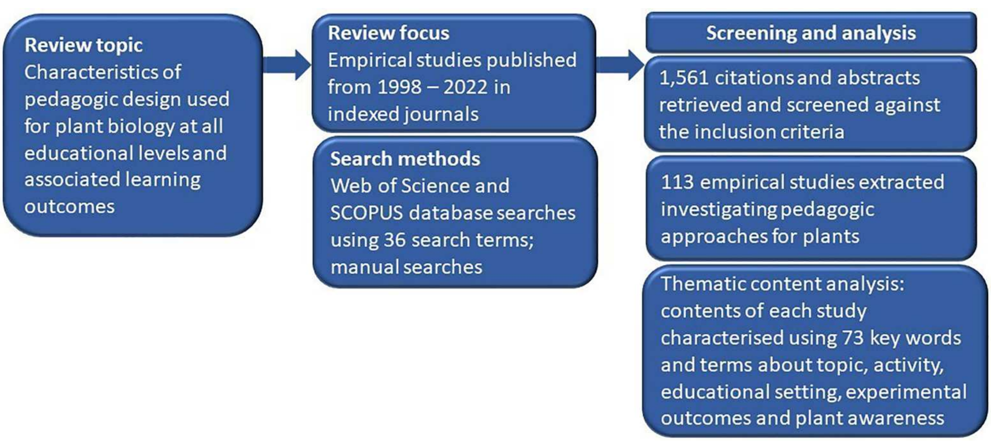

Figure 1. Overview of research methodology.

Table 1. Search terms for literature searches (reproduced from Stagg & Dillon, 2022).

'plant blindness', ' animals more interesting than plants', 'prefer animals to plants', 'attitudes towards plants', 'perceptions of plants', 'attitudes towards trees', 'interest in plants', 'zoocentrism', 'zoocentric', 'zoo chauvinism', 'plant neglect', 'botany education', 'plant education', 'plant science, education', 'horticultural education', 'learning plant', 'teaching plant', 'teaching botany', 'Plant knowledge', 'botanic gardens, education', 'photosynthesis, education', 'educational gardening', 'school gardens', 'gardening, education, plant', 'school gardens, education, plant', 'community garden, education, plant', 'fern, education', 'bryophyte, education', 'gymnosperm, education', 'moss, education'

overarching account of the focal research area, as a pragmatic choice for a review of literature encompassing a wide range of research designs (Popay et al., 2006). The account was based on rich description that explored multiple points of view and supported by tables depicting the main trends in the dataset. These review methods were informed by Bennet et al.'s (2005) critique of review methods for education, and Davies et al.'s (2013) review of creative learning environments in education.

The following literature searches were undertaken: (1) Searches using bibliometric databases *Web of Science*, *Directory of Open Access Journals* and *Scopus* based on the search terms (Table 1); (2) Searches of leading research journals in science education using select search terms; (3) Manual examinations of reference sections of key studies, conference proceedings and reviews, including a search of citing articles for pre – 2010 studies.

Altogether, 1,561 citations and abstracts were retrieved using the search methods. Titles and abstracts were screened against the inclusion criteria (Table 2), with examination of the full paper where this was not sufficient. A randomly selected sample of >5% was double screened by a researcher colleague as a reliability measure (Bennett et al., 2005). There was 100% agreement between the two assessors for the screening, meaning it was not necessary to calculate an inter – assessor correlation coefficient. Studies were downloaded from university library websites or, when unavailable, ordered from the British Library.

A total of 113 studies were identified for review. A thematic analysis was used to characterise the reviewed studies, informed by Neuendorf (2019), and based on an initial suite of *a priori* codes which were developed and revised upon close examination of a sample of texts. The coding scheme (Online Supplementary File 1) was composed of two sections. The first, characteristics of the intervention, e.g. type of learning activity, location, topic, outcome, initially based on Jeronen et al.'s (2017) review of biology education. The second, the variables of plant awareness, which are explained in this study's introduction. A randomly selected 5% sample of studies were replicate-screened and

Table 2. Inclusion criteria for literature screening.

Category	Criterion
Topic	Design and evaluation of a novel intervention that aims to contribute to cognitive and/or affective learning about plants, in any educational context
Population	Any type of learner and age group, apart from plant experts/specialists
Article type	Original research indexed in *SCimago Journal Rank or Clarivate Science Citation Index Expanded* or *Directory of Open Access Journals*
Language	English
Experimental design	Experimental/quasi-experimental study based on qualitative and/or quantitative methods
Scope	International research
Time period	Published between 1 May 1998 and 31 December 2022

coded by a researcher colleague as a reliability measure following Bennett et al.'s recommendations. The inter-coder agreement was assessed using Krippendorff's Alpha, resulting in a value of 0.94, indicating a high level of agreement.

Results

Characteristics of the reviewed studies

Studies were undertaken in a total of 33 different countries, with a majority in the USA and UK (Figure 2). A quarter of the studies were published in *The Journal of Biological Education* (Figure 3(a)). Just over half (56%) were based on a pre–post-test design and 48% compared an experimental intervention to a control one. The mean population sample size was 200 participants and mean intervention length 12 hours in total. Most studies were carried out with high school pupils (Figure 3(b)). The most common learning activities were identification keys, laboratory investigations, and class or small group discussions (Figure 3(c)). See 'Online Supplementary File 2' for descriptions of learning activities and example studies.

Half the studies included outdoor learning as part of the intervention, for example in the school or campus grounds (Figure 3(e)). Half the studies focused on biological identification/taxonomy, with each of the other topics covered by less than 20% of studies (Figure 3(d)). Most studies tested the impact of the intervention on learning using a written assessment and/or feedback questionnaire (Figure 3(f)).

Investigations of plant awareness in the reviewed studies

Just over half of studies did not mention plant blindness or plant awareness at all, 33% briefly referred to the concept in the introduction and/or discussion, and 14% referred to the concept throughout the study and considered it in the experimental design. A total of

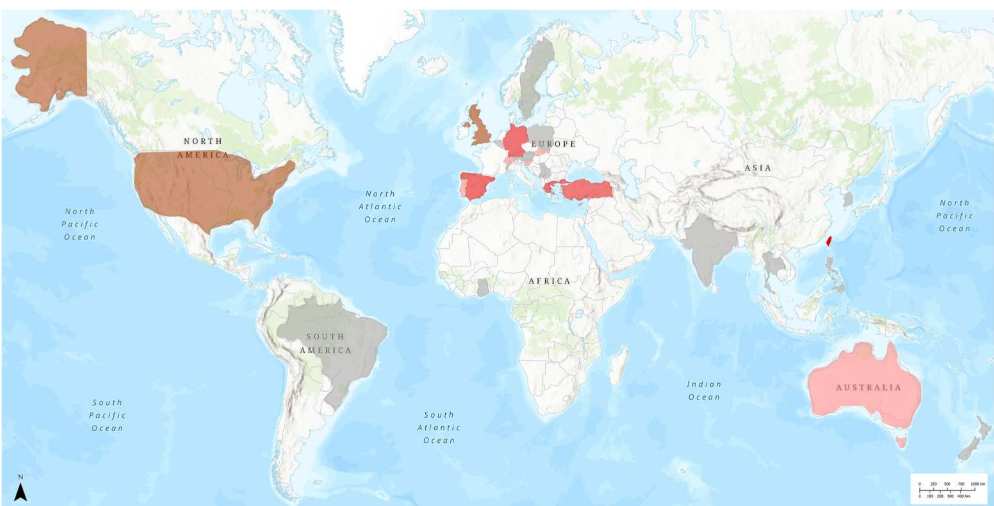

Figure 2. Distribution of published studies (brown: 15–30 studies, red: 5–15 studies, pink: 3–4 studies, grey: 1 – 2 studies).

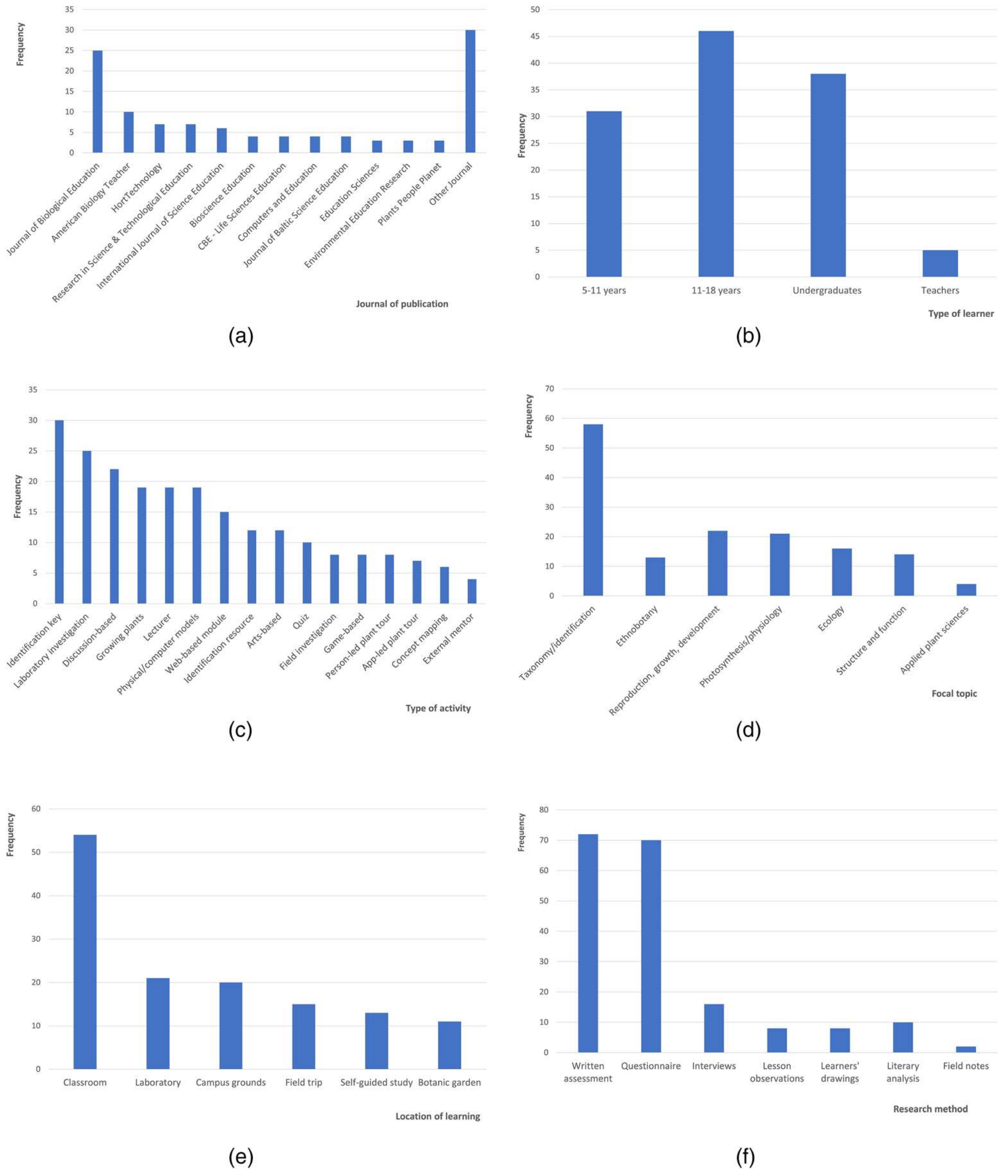

Figure 3. (a). Journal of publication. (b) Target audience. (c). Type of learning activity. (d) Location of learning activity. (e) Focal topic. (f) Type of research method.

31% of the studies that did not mention plant blindness were published before 2010, compared to 10% for those that did mention it.

Perceptual attention

Forty-five studies provided first-hand experience with plants in local environments, the majority learning species identification using keys, often combined with guided observations, games, and quizzes, with eight studies based on field investigations. According to our theoretical framework, visual experience accompanied by relevant linguistic information contributes to memorisation, and 27 studies evidenced a short-term increase in identification skills. Ten studies also found that learners noticed plants in the local environment more frequently after participation. Lindemann-Matthies (2006) found a correlation between the number of plants children noticed and the total time spent observing plants. Observing local plants over time or seasons will strengthen memories of plants, which was the case for street trees (Wyner & Doherty, 2022) and habitat areas in school grounds (Beasley et al., 2021). These are forms of retrieval practice, which, based on our theoretical framework, contributes to perceptual attention for plants.

An innovative retrieval practice was used by Wandersee et al. (2006); a writing template with 'memory prompts', to stimulate childhood memories of plants. Survey data indicated that this exercise helped to reactivate positive associations and resulted in renewed attention for species. Stagg and Donkin (2016) tested a recognition approach based on mnemonics, visual cues linking a species name with its appearance. Mnemonics resulted in higher identification test scores than using keys, which theory suggests is because they provided more meaningful or accessible mental models for species.

The attention required for the accompanying task will influence how much attention can be allocated to the plants. Studies that piloted novel printed or digital keys assessed usability based on navigability of the design and clarity of the linguistic and visual content (e.g. Stagg, Donkin & Smith, 2015). Usability provided a useful proxy measure for perceptual load, and many studies found that low usability was associated with poor identification test scores, suggesting that perceptual load had limited the attention available for observing and memorising plants, as predicted by our theoretical framework. The design and content of learning tools were more important than presentation medium for predicting usability, with technical difficulties or extraneous features increasing perceptual load. Six studies investigated the drawing of plants, which might be expected to enhance mental representations by promoting in depth observation, but Stagg and Verde (2019) found that drawing was only valuable for memorisation for learners that were confident artists, perhaps because these learners were less distracted by the task.

Six studies evaluated self-guided tours of campus or botanic gardens using a mobile app. Plants were tagged with Quick Response codes for accessing relevant information or tasks, reducing the perceptual burden of navigating around a learning tool. Some tasks promoted in-depth observation, by requiring the learner to count floral structures, for example. One app was based on audio tracks, which could reduce perceptual load by allowing visual attention to be focused on the plant (Kissi & Dreesmann, 2018). The app also provided tailored feedback based on students' responses, rendering the interactions with the plants more meaningful. Retrieval practice featured in many digital learning tools as quizzes. Some studies combined outdoor learning with retrieval practice on return to the classroom, for example production of information plaques about the plants observed (Lai et al., 2007). The same app included a feature guiding the learner through an exercise experiencing the plant with all the senses, which significantly increased identification knowledge and perceptual attention, compared to the control. Burrows et al. (2014) designed an app comprising photograph-based quizzes mimicking the process of holistic recognition that experts use to recognise plants. This process is akin to facial recognition and contrasts with the process promoted by an identification key, of examining separate features in turn. They found that the app produced a superior improvement in identification skills compared to the traditional approach.

As predicted by our theoretical framework, the intrinsic qualities of plants contributed to their visibility and memorability. The plants that attracted most attention or were most memorable were those with unusual adaptations or sensory characteristics (Nyberg & Sanders, 2014), cultural relevance for learners (Bowker, 2007) or bright colours (Prokop et al., 2016).

Interest

Sixteen studies identified an increase in interest in the learning activity, 13 identified an increase in interest about plants and 15 found an increase in motivation, following the intervention. Two thirds of studies were based on questionnaires with less than five items. Several studies also measured enjoyment, and generally there was a positive association with interest. Questions/items were either based on triggered situational interest, the initial stage of interest development, for example: 'how interesting would you say this plant is?' (Strgar, 2007) or maintained situational interest, for example: 'I am planning to continue growing plants in the future' (Krosnick et al., 2018) or 'I would like to visit another botanic garden' (Kissi & Dreesmann, 2018). Four studies were based on Fančovičová and Prokop's (2010) Plant Attitudinal Questionnaire, which includes 10 items about interest (mostly maintained). None of the studies assessed whether participation had led to a real behavioural change but were based on intention alone.

In keeping with our theoretical framework, the qualities of the focal plants and learning environment were important factors in interest development, including plants with unusual or surprising adaptations (Strgar, 2007), novel sensory characteristics, including odour and tactile structures (Stagg, 2020). Stimulant herbal and spice plants triggered situational interest in students with low prior interest but not in students with existing interest, which the authors attributed to the lack of autonomy in the activity (Pany et al., 2019).

Seven studies sought to increase interest by drawing attention to plants' active behaviours and movement, for example, time-lapse videos capturing plants directional responses to environmental stimuli, which increased both immediate interest and a desire to investigate plants in the future (Brenner, 2017). A study based on a learner-guided enquiry about chemical defence mechanisms in chilli plants led to a substantial increase in interest in plants, as organisms that could defend themselves and respond to stimuli (Nantawanit et al., 2012). More recently, Guerra et al. (2024) have shown that observing plants moving on a human time scale increased motor system activity.

Psychological needs and interest

Eight studies measured one or more of the psychological needs that, in our theoretical framework are associated with interest development, namely perceived competence, autonomy, and relatedness (Ryan & Deci, 2000). Students reported a higher sense of competence using a paper-based key compared to a digital identification app, which authors attributed to the higher complexity and number of choices that had to made for the digital key (Finger et al., 2022). However, there was no difference in the levels of interest and enjoyment reported for the two identification resources. Younger children found a mobile identification app more challenging to use than older children but reported higher levels of interest (Kissi & Dreesmann, 2022). Students' levels of perceived competence, autonomy, and relatedness were positively correlated for learning based on a quiz-based mobile app but the influence on levels of interest were not directly measured (Nikou & Economides, 2016). A mobile learning app was found to promote a greater sense of relatedness than a printed resource because the novel tool served as an 'icebreaker' that triggered interactions between students and fostered collaborative working to a greater extent than the traditional tool. Two studies found that authentic research investigations led to increases in perceived competence, which one (Hiatt et al., 2021) attributed to the instructors' pedagogic abilities, as opposed to instructional design.

Attitude

Fifteen studies assessed the impact of the intervention on attitudes towards plants, with three further studies investigating the impact on attitudes towards science. Half the studies were based on a small number of questions about liking or disliking plants or their importance to humans, with the rest employing multi-item questionnaires or interviews. Most studies provided first-hand experience with plants, including growing plants and planting trees, often alongside novel experiences known to generate positive affect, for example drama (Stagg, 2020), craft activities (Cil, 2016) and authentic research (Hiatt et al., 2021). The latter study investigated learning based on native plant gardens for studying phenology, laboratory investigations about 'charismatic' plants and experimental plots to investigate impacts of environmental change on plant composition.

Six studies focused on growing native, food or ornamental plants as part of investigative work over an extended period, in the classroom, laboratory or home. In all studies, the leading theme for what students liked most about the experience was the sense of caring for and nurturing a plant and watching it flourish, indicating an emotional reaction to plants akin to empathy (e.g. Krosnick et al., 2018). Plants were also perceived as more attractive after raising plants from a soil seed bank (Ju & Kim, 2011) and cultivating pea seedlings (Nyberg & Sanders, 2014). Plants were described using anthropomorphic or animalistic terms, for example: 'it was like a little pet' (Krosnick et al., 2018).

Seven further studies focused on interventions to raise awareness about the importance of plants for the biosphere or human affairs, using visits to botanic gardens, arts integration with plant science and multimedia online courses. Online courses introduced the importance of endemic plants for conservation (Petrou & Korfiatis, 2013) and plants for energy production and carbon sequestration (Valle et al., 2021). The latter study was based on three approaches, citizen science, storytelling, and inquiry-based learning, and learners found the storytelling to be the most useful and enjoyable approach of the three.

Knowledge

Seventy-seven per cent studies identified a quantitative or qualitative improvement in cognitive learning, relative either to a pre-intervention assessment or a control. Most studies focused on information recall but a third investigated learners' comprehension, conceptual understanding or ability to apply learning in novel situations. Thirteen studies found that a computer-based resource was superior for cognitive learning compared to a traditional one. Six studies found that an intervention based on living plants was superior to one based on dried plants, photographs, or text. Five studies found that inquiry-based learning was superior to an alternative method, and three that an outdoor learning approach was superior to an indoor one.

Discussion

Relative coverage of topics and pedagogic approaches (RQ1)

The pedagogic approaches demonstrated the important role of social constructivist approaches for learning in science, including the value of outdoor instruction, inquiry-based and computer-assisted learning discussed elsewhere (e.g. Dillon, 2014). There was a strong bias to species identification in coverage, a surprising outcome as this subject is neglected in undergraduate teaching and school curricula (Stroud et al., 2022) but could be indicative of an attempt by researchers to address this deficit. Outdoor learning, another often-neglected practice, occurred in nearly half the studies, due mainly to the bias to identification skills, which are normally taught in the field. Most studies were based on school or undergraduate students. A minority of studies was undertaken with qualified or pre-service teachers, a concern since teachers' plant awareness has been highlighted as an area requiring attention (Stagg & Dillon, 2022). One reason for this trend could be the brevity of teacher training in many countries, which provides limited opportunities for educational research but could be addressed using 'teacher as researcher' approaches, including action research.

All studies focused on formal learning, apart from Stagg and Donkin (2013), Stagg et al. (2015), Stagg and Donkin (2016) and Stagg and Verde (2019). studies about lifelong learning. Family learning would be a valuable area to explore for plant awareness, as there is substantial evidence that plant awareness stems from family experiences and childhood (e.g. Wells & Lekies, 2006). Effective approaches for family learning that merit exploration include wild food foraging and crafts (Stagg & Donkin, 2013).

Consideration of plant awareness in the reviewed studies (RQ2)

Half the studies failed to mention 'plant awareness' or related terms and only a minority of studies made more than a passing reference to these terms. Two thirds of the studies measured one or more variables relevant for plant awareness, indicating that authors considered plant awareness in the broader sense to be important to their enquiry but omitted the literature-defined terms. There were indications that the use (or not) of literature-defined terms was influenced by age of study and geography but, for those researchers that mentioned the terms but did not investigate it in depth, we should assume either that they did not know that it is a multi-dimensional construct with validated measurement scales or considered it to be of limited importance to their enquiry.

A theoretical basis for pedagogical practices that increase plant awareness (RQ3)

Our theoretical framework about perceptual attention, interest, attitude and learning proved to be a valuable fit for the literature. The focus on species identification in the review allowed for an in-depth examination of how different interventions offering first-hand experience with plants strengthened mental models for plants and perceptual attention (Figure 4).

Embodied learning, experiences based on sensory-motor processes, helped strengthen mental representations by providing a rich and deep experience of plants (Foglia & Wilson, 2013) but was explored in only a few studies. Embodied learning could help to overcome the perceptual challenges posed by the uniform colours or textures of many plants (Sanders et al., 2022).

One element of perceptual attention not considered in the reviewed literature was the influence of existing mental representations on attention. A non-experimental study (Comeau et al., 2019) investigated children's mental models of plants using drawings and found that children's pre-existing, inaccurate perceptions about plant structures impeded their ability to detect and depict the accurate characteristics of the plants observed. This outcome highlights the importance of understanding learner preconceptions and was added to the model in Figure 4.

Few identification studies were based on investigative fieldwork, with Goulder and Scott's (2006) study about learning identification through habitat surveys a notable exception. Students prefer to learn plant identification through authentic inquiry which has been shown to be an effective approach (Palmberg et al., 2019). It is also a requirement in the 14–18 biology curricula in many countries, including England (Department of Education, 2015). Ecological skills development is neglected in formal and higher education, leaving many people poorly equipped to respond to environmental change and rapid biodiversity loss (Cooke et al., 2021). This element of learning was added to the model in Figure 4.

A sub-sample of studies promoted interest development through the choice of plants and instructional design that drew attention to striking or surprising features (Figure 5). Studies assessed interest using behavioural intent, with no studies following up subsequently to see if participation had led to an actual change in behaviour. This

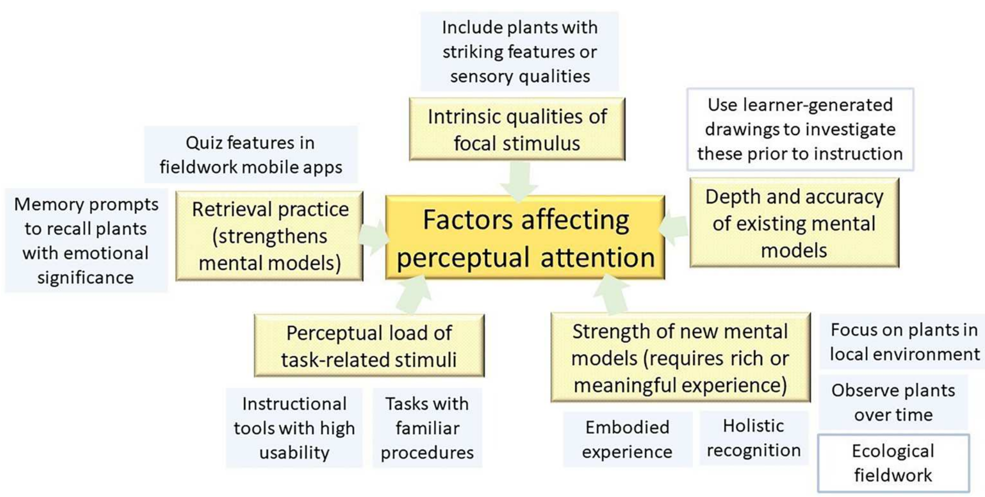

Figure 4. Proposed model for increasing perceptual attention for plants. Elements of theory are shown in yellow and findings from the reviewed studies are shown in pale blue.

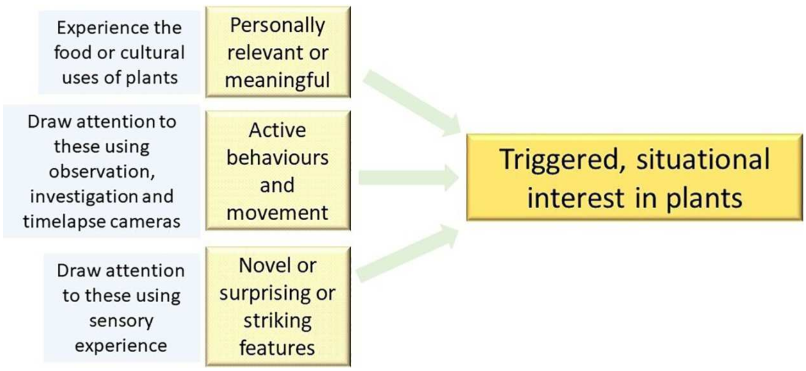

Figure 5. Proposed model for developing triggered, situational interest. Theoretical elements are shown in yellow and findings from the reviewed studies are shown in blue.

represents a lost opportunity and could have been combined with delayed knowledge tests. There was evidence that instructional design influenced learners' psychological needs but limited insights into how these were related to interest development.

First-hand experiences with plants led to an increase in positive attitudes, particularly when combined with novel approaches known to promote enjoyment (Figure 6). Growing and caring for plants developed positive affect and empathy for plants. Balding and Williams (2016) proposed that encouraging empathy should be a priority pathway for increasing plant awareness and empathy is the central focus of the 'nature connectedness' construct, which focuses on people's affinity with nature (Lumber et al., 2017). Balding and Williams considered anthropomorphism to be a valid route to empathy, at least as a starting point and if treated with caution. Parsley et al.'s (2022) measurement scale included a factor focusing on the positive affect and the caring for and investment in plants, a useful instrument for investigating this aspect of plant awareness further. Burke et al. (2022) drew attention to the potential role of plant-themed social media platforms for increasing plant awareness in young adults. School gardening has become an increasingly popular practice but featured in only a minority of studies in the review. Many of the studies on this topic that were extracted and assessed did not investigate the impact of the intervention on learning about

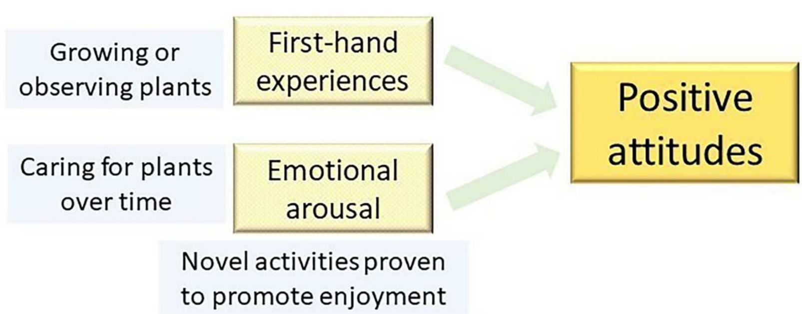

Figure 6. Proposed model for promoting positive attitudes about plants. Theoretical elements are shown in yellow and findings from the reviewed studies are shown in blue.

plants but focused on healthy eating or social skills. It would be valuable for educational researchers to collaborate with horticultural practitioners to address this gap.

Methodological weaknesses in the review

Few studies used a validated measurement scale for measuring plant awareness, relying instead on questionnaires with a small number of response items, no measures of internal consistency and little consideration of affective traits. The paucity of affective data, and data based on rigorous measurement scales limited our ability to compare potential interactions between the different plant awareness variables.

Where included, the meaning or interpretation of affective traits was often unclear and did not follow the accepted definitions, a common problem in science education (Koballa & Glynn, 2010). Studies were overly reliant on self-report items and did not make use of less biased alternatives like recall and categorisation tests. There was a paucity of studies employing mixed methods or qualitative approaches, constraining the pedagogic insights that can be drawn from this review. The most used qualitative method was the inclusion of open-ended questions in questionnaires, which offer limited scope for emergent insights, compared to interviews and learner-generated drawings (Koballa & Glynn, 2010). A third of studies assessed the effects of the intervention on cognitive learning but with no measurements in the affective domain at all. These findings are probably partly due to the lack of time or access to learners for qualitative assessments but also suggests a potential skills gap in researchers' methodological designs. Many researchers will be biology educators and potentially lack expertise in social science research methods and paradigms.

Plant awareness in the broader (non-experimental) literature

Our broader literature extraction identified 32 correlational research studies and 48 non-empirical (essay/opinion) articles about plant awareness. Many of the pedagogic recommendations in these studies are not being picked up by the experimental research. Some papers described novel learning activities or resources they had designed and implemented but not evaluated empirically. Innovative ideas included celebratory meals on campus to raise plant awareness (Moscoe & Hanes, 2019), novel 'flagship' species with iconic associations (Meyer et al., 2019) and educational boardgames (Friedersdorff et al., 2019). Other innovations outside of the scope of this review include those in the *Science and Plants*' resource bank for schools (https://www.saps.org.uk/).

Educational implications

The models (Figures 4–6) could be developed into an informal framework for assessing the potential contribution of lesson plans and schemes of work to plant awareness. The models' key concepts informed the design of the lead author's 2023/4 programme of teacher CPD and online course (Figure 7 and https://bit.ly/42gwiLS) These approaches supported perceptual attention, interest, and attitude by providing memorable or rewarding experiences and by drawing attention to notable plant features and

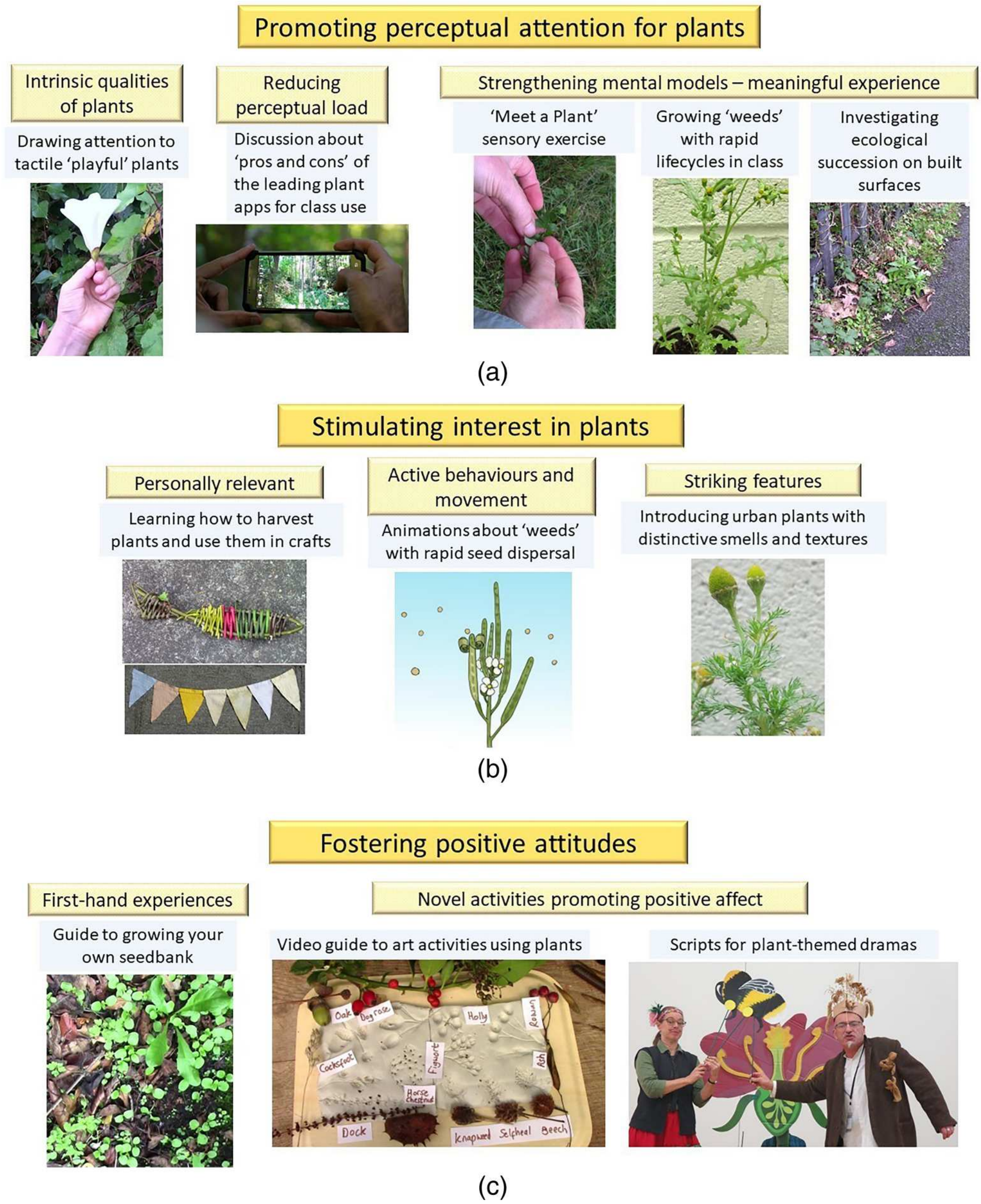

Figure 7. (a) Elements in teacher CPD programme promoting attention to plants. (b) Elements in programme promoting interest in plants. (c) Elements in programme fostering positive attitudes towards plants.

behaviours. The approaches are discussed in Stagg and Donkin (2013), Stagg et al. (2015), Stagg and Donkin (2016) and Stagg and Verde (2019).

Models could also be used in conjunction with the plant awareness measurement scales discussed in this study, to monitor progress and actual contribution of learning to these goals. Plant pedagogies have focused on principles of social constructivism to date, rather than the dimensions of plant awareness, so these models provide a valuable addition to existing frameworks. There is also a dominant assumption in biology education that knowledge generation will automatically lead to plant awareness, which these models help to challenge and address.

Conclusion

This review study summarised the relative coverage of different topics of plant biology in educational research, the pedagogic approaches used and the extent to which plant awareness was considered in this field of enquiry. There was a focus on species identification, outdoor learning and general pedagogy, with limited consideration of the concept of plant awareness. A minority of studies assessed affective learning in a rigorous way, highlighting a potential skills gap in methodological design in this research field. There was a paucity of studies that investigated the impact of the intervention on durable interest development or other facets of behavioural change, a significant limitation for developing our understanding of how to foster plant awareness. The review highlighted important gaps in experimental research for this field, namely instructional approaches targeting in-service and pre-service teachers, the role of investigative fieldwork for learning plant identification, or the potential for school gardening and informal learning contexts to increase plant awareness. We recommend that future research focuses on these areas.

We developed a novel framework based on theories of perceptual attention, interest, attitudes and learning to examine the literature, yielding interpretations and insights for increasing plant awareness in education and a basis for how educational interventions might be designed and evaluated. First-hand experiences were important for promoting attention, interest, and positive attitudes to plants, particularly in combination with instructional approaches that provided immersive or prolonged experience with plants and generated positive affect. We believe that these theoretical advancements should be considered in future studies about plant awareness.

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Data access statement

This study did not generate any new data.

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