Developing a Pedagogy for Reducing 'Plant Blindness'

Submitted by Bethan Claire Stagg to the University of Exeter

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ……………………………………..

Acknowledgements

With thanks to my PhD supervisors, Professor Justin Dillon and Dr Lindsay Hetherington, for their invaluable advice and guidance. You helped me to mature into a doctoral level researcher.

I would also like to thank all the many volunteers that participated in the educational sessions, as well as my funders (Big Lottery Fund, The Linnean Society of London and The Wildflower Society). This research would not have been possible without your support and interest.

And finally, a big thank you to my family: to my co-author and husband for supporting me in every way possible; to my parents, for inspiring me with a love of plants from an early age; to my son, for being you. Ewan, you were my inspiration for embarking on a PhD. I wanted to show you that not only dads get doctorates and to make you proud of your mum.

Abstract

Despite human dependence on them, inattention to plants or *plant blindness* is a well–known phenomenon in urban societies. This thesis investigates the efficacy of a suite of novel teaching approaches for botany with adults and children and considers how these published research–based resources can contribute to a pedagogy for reducing plant blindness, in conjunction with the existing literature. This research was based on a mixed methods design using knowledge tests, questionnaires and interviews. It focused on two themes: novel methods for learning taxonomy (digital keys, mnemonics, drawing and game–playing) and drama–based methods for learning reproduction and classification. The literature review examined the characteristics of plant blindness and its impacts on teaching and learning. The fundamental cause of plant blindness was shown to be diminished experience with plants in urban societies which leads to low interest in plants compared to animals. A majority of pedagogic studies were based on learning with live plants, many of which were inquiry-based learning. Half the studies included outdoor learning and half used digital learning approaches. A content analysis of published research using themes based on theories of embodied cognition, memory and positive affect found the textual data to be evenly distributed across all three themes. The pedagogic approaches promoted learning through elaborative techniques, instructional tools with high usability, multimedia experiences and emotional wellbeing. Drawing and keys favoured observation over other perceptual modes, whereas drama facilitated multisensory experience. The research identified physical and cognitive factors that may assist or impede learning. A theoretical contribution of the research was the application of memory theory to learning taxonomy, advancing our understanding of how the design of keys and mnemonics may assist retention. Drama studies enhanced our understanding of children's attitudes to plants and how a brief intervention may address these.

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Author's declaration

Study citation	**Nature of author's individual contribution**	**Extent of author's individual contribution**
Stagg & Donkin (2013)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. I explained the experimental design verbally to the Donkin prior to testing and sent her successive paper drafts, paper submission and proof. In all cases, she made a small number of suggestions verbally or in writing, but did not make any in–text corrections.	95%+ Stagg: 1,200 hours; Donkin: 6 hours approx.
Stagg, Donkin, & Smith (2015)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. I explained the experimental design verbally to the Donkin and Smith prior to testing and sent them successive paper drafts, paper submission and proof. In all cases, Donkin made a small number of suggestions orally or in writing, but did not make any in–text corrections. Donkin also chaired a lunchtime piloting event, for the draft versions of the computer and printed keys used in this study. Smith contributed as follows: • Verbal and written feedback on experimental design and draft versions of the identification keys • Co–ordinated the five educational sessions, including instruction of participants, experimental delivery, data collection and associated logistics • In–text comments and corrections for one paper draft • Verbal comments on the subsequent, corrected draft	95%+ Stagg: 1,200 hours; Donkin: 8 hours; Smith: 25 hours approx.
Stagg & Donkin (2016)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. I explained the experimental design verbally to the Donkin prior to testing and sent her successive paper drafts, paper submission and proof. In all cases, she made a small number of suggestions verbally or in writing, but did not make any in–text corrections.	95%+ Stagg: 1,200 hours; Donkin: 4 hours approx.
Stagg & Donkin (2017)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. I explained the experimental design verbally to the Donkin prior to testing and sent her successive paper drafts, paper submission and proof. In all cases, she made a small number of suggestions verbally or in writing, but did not make any in–text corrections.	95%+ Stagg: 1,200 hours; Donkin: 6 hours approx.

Stagg & Verde (2019a)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. Verde contributed as follows: (1) Verbal feedback on experimental design (2) In–text comments and corrections for two paper drafts (3) Coded a proportion of the data to provide measures of inter–coder reliability, where subjectivity in coding was a potential issue (4) Verbal feedback on reviewers' comments, following submission	95%+ Stagg: 1,200 hours Verde: 15 hours approx.
Stagg & Verde (2019b)	I designed, conducted, analysed and wrote up the study for submission. I corrected all subsequent revisions and proofs for resubmission. Verde contributed as follows: (1) Verbal feedback on experimental design (2) In–text comments and corrections for 2 paper drafts (3) Coded a proportion of the data to provide measures of inter–coder reliability, where subjectivity in coding was a potential issue (4) Verbal feedback on reviewers' comments, following submission	95%+ Stagg: 1,200 hours; Verde: 15 hours approx.
Stagg (2019)	Sole author	100%

Professor M. E. Donkin retired in 2016 and is unable to contribute to this statement due to chronic illness. Therefore Dr A. M. Smith has contributed to this statement on her behalf. As well as being a co–author, Dr Smith was my colleague from 2010–2013 and was supervised by Prof. Donkin for her PhD and in her job role for the OPAL project.

I validate that this is an accurate statement of the nature and extent of the author's (Bethan C. Stagg) contribution to papers co–authored by myself and/or Maria E. Donkin:

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Date: 7/4/2020.

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I validate that this is an accurate statement of the nature and extent of the author's (Bethan C. Stagg) contribution to papers co–authored by myself:

Signed: ………………………………………………… Name: Dr Michael F. Verde
Date: 11/04/2020.

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1. INTRODUCTION

1.1 Rationale: Personal, professional and academic

My own interest in plants started at a young age and grew as a result of the out–of–school learning opportunities available to me. I germinated fruit pips using *The Pip Book* (Mossman, 1977), I filled the family greenhouse with cacti grafting experiments, and I visited Kew Gardens and dreamt of becoming a 'plant hunter'. In contrast with studies on motivation and early interest in science (Maltese & Tai, 2010; Osborne, Simon, & Collins, 2003), my school experiences did not, I feel, contribute significantly to my interest in botany. Whilst I enjoyed school biology, I felt more inspired by the gardening and botanising that I undertook in my own time.

I enrolled for a Botany degree at Bristol University but, discouraged by the small cohort (just two students), soon switched to the Biology degree. In 2010, Bristol became the last British university to withdraw its botany degree due to low enrolment rates (Drea, 2011). I subsequently worked in various roles in environmental education and completed a Master's degree in Biodiversity and Conservation at Leeds University. I regained my interest in botany through a growing passion for allotment gardening and human plant uses. I have since worked as an ecology lecturer in further and higher education, and currently hold an advisory role in agricultural botany.

The key difference between my formal and informal education was in how I encountered plants. In informal contexts I experienced a diversity of plant species, with the time to observe and appreciate their differing physical identities and sensory cues. In school, plants were often presented as a generic life form or isolated tissue that served to illustrate biological processes and concepts. Other authors have highlighted this issue, for example, Schussler Link-Perez, Weber, & Dollo (2010) showed that plants in biology textbooks were more frequently described using morphological terms, whilst animals were described by taxon.

An important aim in my own teaching practice has been to introduce learners to plants holistically, as a way of stimulating interest. In common with Goulder and Scott (2006; 2009), I discovered that students were deterred from learning to identify plant species by the technical language and difficult

identification keys. Learners were denied the opportunity to enjoy the plant in its entirety, through the reduction of the plant to its morphological components.
I designed and produced novel keys and alternatives to keys, for example, memory games with the aim of overcoming these problems. I have also used teaching approaches based on the sensorial experience of plants, for example, crafts and foraging, and drama. This PhD research investigates: (1) how these approaches contribute to learning about botany and might reduce ‘plant blindness; (2) their contribution to an effective pedagogy for botany, alongside the existing literature.

1.2 Overview of Thesis Design

This thesis is based on a suite of linked empirical studies investigating different practical teaching methods for botany. All studies were published in indexed journals from 2013–19. I have grouped the seven studies into two inter-connected themes, in conjunction with a literature review and a theoretical framework.

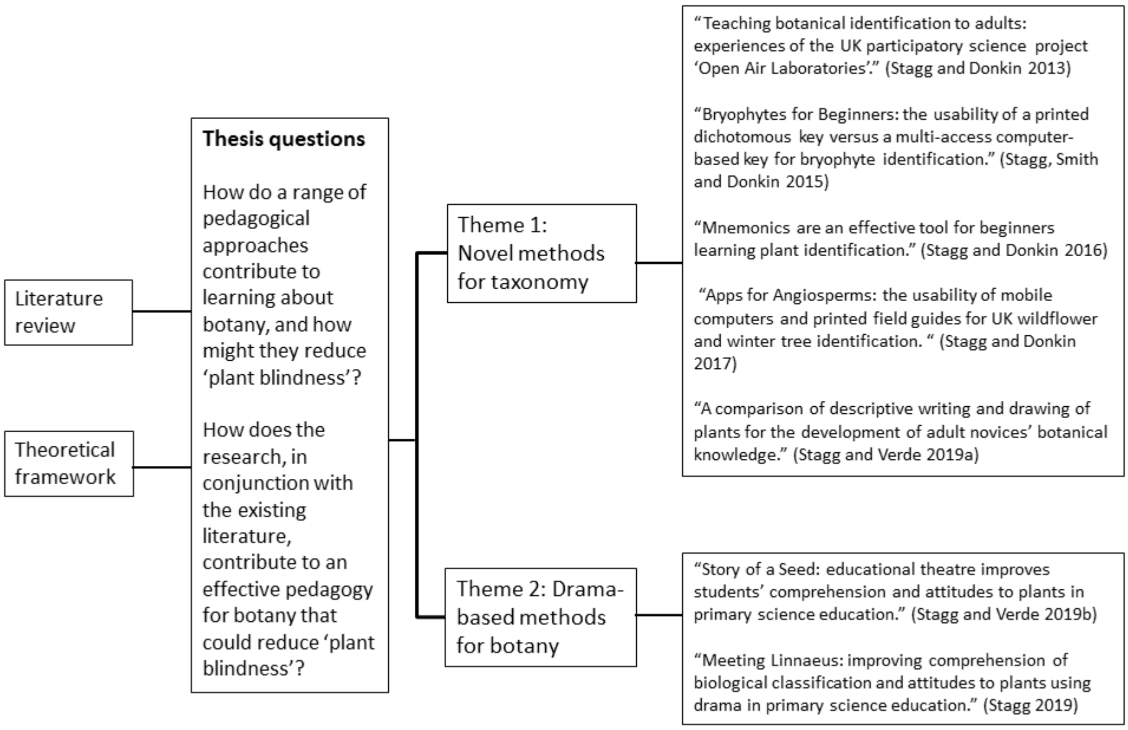

Figure 1. Thesis structure (based on Bowker, 2010)

1.3 Literature Review

The literature review for this chapter was designed to be a comprehensive and critical examination of 'plant blindness' and pedagogic approaches for botany, whereas the literature reviews for the published studies were specific to the area of teaching and learning under investigation. For this review, I used systematic review methods as these tend to be more thorough and objective than the narrative approach typically used in this area of study (Bennett, Luben, Hogarth & Campbell, 2005). The review methods used in this study were informed by Bennett et al. (2005) and Davies et al. (2013).

The stages in the review process and key themes are summarised in Figure 2. Key themes are discussed in detail below. The search terms, inclusion criteria, key words and themes in the thematic content analysis are presented in Appendix 1, as well as the stages in the review process.

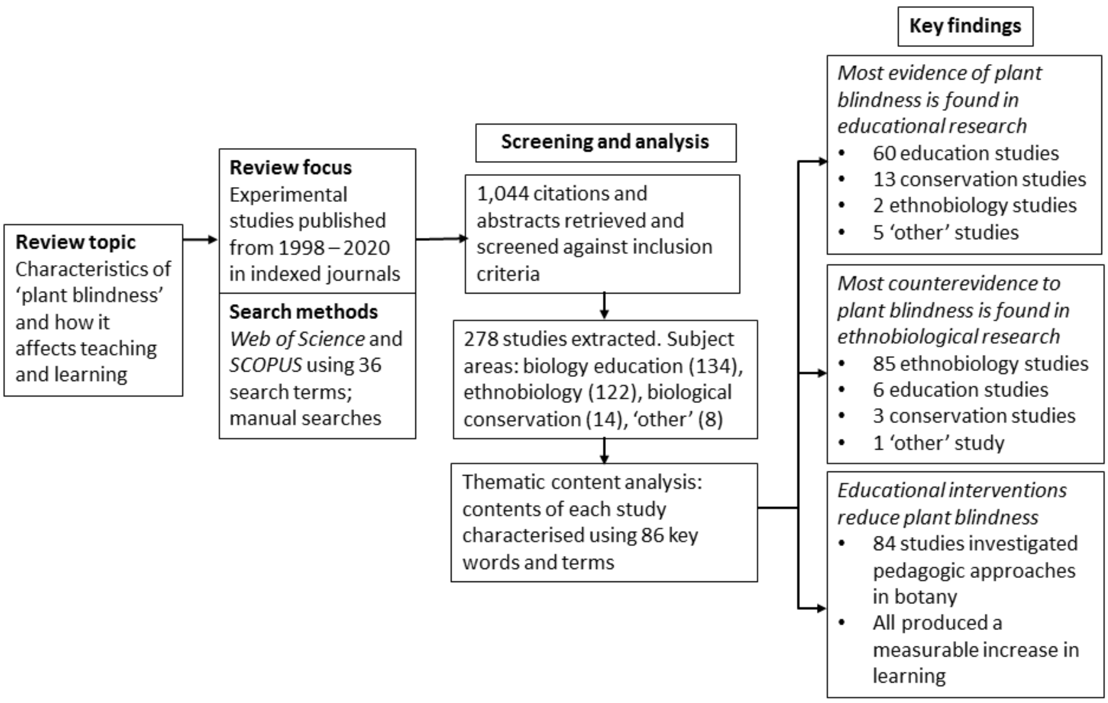

Figure 2. Stages in the review process and key findings

1.3.1 What is plant blindness?

The declining interest in plants is an established concern amongst biology educators. US botanical educators Wandersee and Schussler described this phenomenon as ‘plant blindness’ and defined it thus:

> (a) the inability to see or notice the plants in one’s environment; (b) the inability to recognize the importance of plants in the biosphere and in human affairs; (c) the inability to appreciate the aesthetic and unique biological features of the life forms that belong to the Plant Kingdom; and (d) The misguided, anthropocentric ranking of plants as inferior to animals and thus, as unworthy of human consideration. (Wandersee & Schussler, 1999, p. 1)

The case for why humans cannot afford to ignore plants or disregard their importance is firmly established. The pivotal role of plant diversity in ecosystem functioning is well understood (Grime, 1998), yet plant species extinctions continue to occur at a rapid rate (Thomas et al., 2004). The plant sciences play a fundamental role in addressing global challenges of food production, environmental degradation and climate change (Bonan, 2008; Fargione et al., 2008; Tilman et al., 2002). Ecological knowledge is a prerequisite for the management of natural resources (Pilgrim, Smith, & Pretty, 2007).

The literature review identified 60 educational studies with one or more types of evidence of plant blindness, based on the symptoms defined by Wandersee and Schussler (1999) (Table 1 below). A total of 17 studies found a lack of knowledge or experience of plant identification, particularly among secondary school children and undergraduates. In most studies, the participants could identify hardly any species, for example, Bebbington (2005). Multiple studies have highlighted children’s lack of knowledge or understanding in basic plant science (for example, Ozay & Oztas, 2003; Vidal & Membiela 2014).

Symptom	Example	No. of studies
A lack of 'hands-on' experience in observing and identifying plants	Poor performance in species identification test	17
	Lack of direct experience of plants in biology education	2
A lack of knowledge or understanding in basic plant science	Poor performance in plant science assessment	20
The ranking of plants as inferior to animals	Bias to animals compared to plants in school curricula or books	5
	Preference for animals compared to plants	6
	Plants considered to be 'less alive' than animals	3
A failure to see or notice plants	Attention or memory advantage for animals compared to plants when tested	10
Lack of appreciation of plants or inability to recognise their importance	Low interest or negative attitudes towards plants	8

Table 1. Symptoms of plant blindness in the reviewed articles (n = 60, not mutually exclusive); only outcomes based on a majority of the population sample or statistical significance are included.

Another common trend that has been reported is a memory advantage or preference for animals compared to plants. In Balas and Momsen's (2014) study, US undergraduates exhibited superior recall of images of animals, compared to plants, which were embedded in rapid sequences of unrelated images. In a related experiment, Kanske, Schönfelder and Wessa (2013) showed that animals had a memory advantage over plants because they induced higher emotional arousal. Children in Germany rated botany as the least popular subject out of 10 biology topics according to Elster (2007).

Plant blindness was reported in teachers as well as students. Six studies have highlighted a lack of basic botanical content knowledge in pre-service and qualified teachers, particularly in primary teachers who had not graduated in a science subject. However, some studies revealed a knowledge deficit in science graduates as well. Half the chemistry and physics teachers tested in Mak, Yip and Chung (1999) did not know grass was a flower and lacked a basic understanding of photosynthesis. Some studies have identified a zoocentric bias in educational media, for example Schussler et al. (2010), as mentioned earlier.

1.3.2 The causes of plant blindness

Whilst there is considerable evidence of a consistent cycle of plant neglect in education, this does not explain the fundamental causes of plant blindness. Wandersee and Schussler (1999; 2001) have proposed that plant blindness is an innate feature of our visual cognition but no empirical studies to support this theory have been found in this review. A few studies claimed to have found evidence of innate plant blindness (for example, Balas & Momsen, 2014) but a key weakness was that they used population samples in highly economically developed countries, which would be subject to cultural influences that cause plant blindness, such as low parental interest in plants. Plant blindness is not found in traditional societies with a high dependence on wild plants for medicine, food, fuel or fibre, in South America, for example. Participants could name and identify the uses of 50 or more plant species in 81 ethnobiological studies in this thesis review (for example, Al-Fatimi, 2019; Chekole, 2017).

Virtually all the studies of plant blindness in this thesis's review were based on urban populations in highly economically developed countries. By contrast, most studies of extensive botanical knowledge were carried out with rural communities dependent on natural resources. Six studies compared rural and urban inhabitants (mainly in Europe) and discovered that plant knowledge was significantly higher in the rural sample (for example, Villarroel et al., 2017). Knowledge was directly correlated with plant experience: 13 studies that identified a gender division for the harvesting and preparation of wild plants found a corresponding variance in knowledge (for example, Sher, Aldosari, Ali, & De Boer, 2015).

Many ethnobiological studies have reported the eroding effects of urbanisation on knowledge, as a cash economy supersedes the reliance on natural resources (for example, Pilgrim et al., 2007). Loss of knowledge was not inevitable, however, in situations where wild plant foraging was still valued due to ethnic identity or beliefs (Schunko & Grasser, 2012). In some instances, novel foraging cultures had emerged in cities, for the recreational or health benefits (McLain, Hurley, Emery & Poe, 2014). Thus a knowledge deficit is not inevitable in urban societies as long as there is regular and meaningful contact with plants.

But why might people in urban societies exhibit a memory advantage or preference for animals compared to plants? Diminished experience might explain the common misperceptions that plants are ‘less alive’ than animals and lack ‘active’ behaviours such as movement and noise. Such perceptions are prevalent in children and are even found in adults (Driver, 2000). A few studies suggested that these misperceptions led to low interest or negative attitudes towards plants, for example, Nantawanit, Panijpan and Ruenwongsa (2011).

Urban dwellers have been shown to prefer species that resemble humans, which might also explain their antipathy for plants. Students’ animal preferences were correlated with the species’ degree of behavioural and physical resemblance to humans (Batt, 2009). Waerstad et al. (2002) identified that the level of empathy for an animal species was correlated with its apparent similarity to humans.

Lack of familiarity is not the only challenge to the visual perception of plants. Plants are morphologically complex and frequently grow in dense aggregates (Kirchoff, 2014), meaning they are less likely to be noticed than other features of the visual environment (Lehrer & Schauble, 2004). Some species and structures are difficult to observe without magnification. Key processes in plant science, for example, photosynthesis, are conceptually difficult to understand (Driver, 2000).

1.3.3 Pedagogic approaches for botany

This thesis literature review identified 84 studies that experimentally tested pedagogic approaches in botany (Table 2 below). A total of 31 studies were conducted with undergraduate students, 30 with secondary-age students, 29 with primary-age students and 10 with adults. A majority investigated teaching methods with live plants, many based on in–depth observation, for example Loureiro and Dal-Farra (2017) (Tables 2-3 below). Many also used educational models, experiments and dialogic approaches.

Most of the teaching methods were based on cognitive or social constructivism models of learning (Kalina & Powell, 2009). Nearly all the learning episodes had a classroom element but half also featured outdoor learning, for example in the school grounds (Nyberg & Sanders, 2014). Half the studies were based on digital learning approaches, as discussed by Webb (2010, pp. 162–176). Half the studies focused on taxonomy (Table 4).

Teaching method	No. of studies
Direct experience of live plants	54
Investigative experiment (field or laboratory)	23
Dialogic (for example, Socratic method)	20
Educational model (for example, animation)	16
Lecture	14
Information retrieval practice (for example, quiz)	10
Multi-media virtual learning environment	9
Game	8
Concept-mapping technique	6
Arts-based	5
Mentoring by expert	2

Table 2. Teaching methods used in the reviewed articles (n=84, not mutually exclusive) (Terms adapted from Jeronen, Palmberg, & Yli–Panula, 2016)

Learning activity	No. of studies
In-depth observation (for example, field journal)	31
Biological identification	19
Laboratory investigation	13
Growing plants	12
Tour of botanic garden	11
Field investigation	6
Guided sensorial exploration	3

Table 3. Types of activity providing direct experience of plants (n = 54, not mutually exclusive)

Topic	No. of studies
Taxonomy	42
Growth and development	15
Photosynthesis	14
Ecology	11
Ethnobiology	8
Structure and function	7
Reproduction	3
Applied Plant Science	3

Table 4. Topics in the reviewed articles (n=84, not mutually exclusive)

Virtually all studies found that the experimental intervention(s) contributed to cognitive learning. Nearly half of the studies reported an increase in positive attitudes, interest or attention towards plants, with the majority based on live plants (for example, Pany et al. 2019), although many outcomes were based on a low number of response items per construct, for example Brenner

(2017) and only a few studies, for example Cil (2015), used interviews to allow for a thorough investigation of affective change.

A total of 39 studies compared different interventions, usually a novel one against the established approach as a control. Inquiry-based learning increased learning more than a lecture with discussion. Digital tools increased learning more than the non-digital method, for example, a mobile device compared to a printed field guide (Huang, Lin, & Cheng, 2010). A major weakness in some studies was that the control was not properly described (Smith & Motsenbocker, 2005), the control appeared to be a simplified version of the usual teaching method (Domingos-Grilo, Reis-Grilo, Ruiz & Mellado, 2012) or the control was unrelated to biology (Fančovičová & Prokop, 2011). Few digital learning studies considered the potential contribution of the 'novelty effect' to the results. Some studies failed to highlight the key limitations of cost and accessibility that affect mobile learning (Lai, Yang, Chen, Ho, & Chan, 2007), or the positive aspects of the non-digital methods, for example drawing (Zacharia, Lazaridou & Avraamidou, 2016).

Overall, this literature review demonstrates that, when engaging methods are used for teaching botany, it is not difficult to reduce the symptoms of plant blindness.

1.3.4 Gaps in the Literature

Nearly half of all educational studies were conducted in the UK or USA, which could have skewed experimental outcomes for the review sample. There were virtually no studies that measured symptoms of plant blindness in resource-dependence societies, meaning we have no comparative data about plant perceptions. A majority of studies about plant blindness and learning focused on knowledge deficit and/or acquisition, neglecting the affective aspects of plant blindness and learning. The majority of pedagogic studies were about taxonomy, meaning that we have a limited understanding of learning for other topics. There was a bias to observation-based approaches in studies about direct experience with plants, with only a few studies investigating multi-sensory approaches, for example Lai et al. (2007). There were also very few studies exploring expert mentoring or arts-based approaches, in spite of the promising results of these for increasing interest and motivation, for example Ward, Clarke and Horton (2014).

1.4 Aims and Objectives of this thesis

This PhD research aims to advance our knowledge and understanding of how instructional design and methods could reduce plant blindness, by promoting learning and enjoyment in botany. The research aims to address some key gaps in the educational literature, whilst building on evidence-based effective practice. The inquiry focuses on two areas of learning: novel methods for learning taxonomy, and; drama-based methods for learning botany.

Taxonomy is a major area of learning in botany and the focus of 50% of the educational studies reviewed. Many were based on identification keys with technical vocabulary, which in my own experience and others' (Hawthorne, Cable, & Marshall, 2014; Kirchoff, 2014), impeded recognition learning and learner interest. I therefore explored alternatives, namely digital and pictorial keys, mnemonics (memorisation aids based on morphological features), observation-based drawing and games. I was interested in investigating drama-based approaches in botany because these are known to be effective in promoting positive attitudes and learning in science education (for example, Abed, 2016) but have not been explored in botany. I developed two approaches based on different drama genres.

Teaching approaches were based on practical work, the most appealing aspect of botany for learners (Reiss et al., 2011; Silva, Guimaraes, & Sano, 2016). Teaching was based on live plants, which eight of the studies reviewed found to be more effective for learning than other approaches (for example, Strgr, 2007). Studies were based on different age groups and plant taxa, to allow learning approaches to be tested in multiple contexts. Learning approaches were adapted according to the age group (Kerka, 2002).

Approaches were classroom based to pilot plant experiences that did not require laboratory and field facilities. Whilst the outdoor environment is arguably the best place to experience plants, fieldwork provision in biology has declined (Tilling, 2018). Plants in the classroom provide easier scope for protracted observations (Nyberg & Sanders, 2014). These approaches may also be used as preparatory exercises prior to fieldwork (see, Pfeiffer, Scheiter, & Gemballa, 2011).

The research questions for this thesis are:

1. How do a range of pedagogical approaches contribute to learning about botany, and how might they reduce ‘plant blindness’?
2. How does the research, in conjunction with the existing literature, contribute to an effective pedagogy for botany that could reduce ‘plant blindness’?

There is, currently, no overall framework or model for teaching and learning botany and this thesis aims to address that gap.

1.5 Theoretical Framework

1.5.1 Rationale

My inquiry examined pedagogic approaches, using lenses of embodied cognition, memory theory and positive affect. I used the first lens because learning with live plants is a physical experience; the second because botany requires a lot of memorisation; and the third because negative affect is a persistent problem in botany.

1.5.2 Embodied learning

Learning with live plants creates a richer experience around the plants for learners to tie their knowledge to. Meaningful processing that evokes strong associations, as well as experiencing materials in multiple modalities, is well known to enhance memorability (Craik & Lockhart, 1972; Keifer & Trumpp 2012; Paivio, 1971). Sensory learning may promote associative memory, whereby a physical stimulus, for example, smell, helps to cue retrieval of the species name (Auer, 2008). Eberbach and Crowley (2009) emphasised the importance of sensory perception for understanding scientific phenomena.

Learning based on plant experience can be viewed in the context of embodied cognition theory: that is, learning that is grounded in the body’s sensory-motor processes, as well as the brain (Varela, Thompson, & Rosch, 2016). Glenberg and Gutierrez (2004) demonstrated that manipulating three-dimensional objects improved children's learning compared to experiences with no manipulation. They posited that manipulation improves learning through the generation of mental models with greater complexity.

1.5.3 Active learning that promotes memorability

The benefits of active learning in science education are well established, with origins in the constructivist learning theories of Dewey, Vygotsky, and others. Identification keys are a valuable form of active learning but, as a complex task, can place demands on working memory that inhibit memorisation (Randler & Birtle, 2008). Keys also divide attention between a variety of objects and phenomena, preventing a focus on the species in its entirety. Activities that promote the examination of plants in their entirety may be more effective according to the theory of feature unitisation (Goldstone, 1998). This theory has been shown to apply to face recognition in perceptual learning (Chua & Gauthier, 2019) and has been successfully applied to plant species recognition by Kirchoff et al. (2014). I used mnemonics and drawing in this research to provide an immersive experience with plants.

Drama is also a form of active learning in science, when it involves physically acting out material (Saricayir, 2010), or inquiry-based learning (Kolovou & Nam Ju Kim, 2020). Drama enables learners to create a richer background context for learning, by creating their own interpretations of the material under investigation (Scott, Harris & Rothe, 2001).

1.5.4 Enjoyment and other forms of positive affect

Enjoyment was a key consideration in thesis instructional design and evaluation. Positive affect and enjoyment have been shown to increase learners' intrinsic motivation and ability to work effectively at a task in science education (Ainley & Ainley, 2011; Isen & Reeve, 2005).There was also a focus on learning media that were culturally familiar to learners in many of my studies, for example, games and mobile devices. Aikenhead (1996) proposed that learner-compatible approaches could help to narrow the gap between the everyday world and the positivist culture of school science. I avoided the technical language and scientific operations known to be alienating for novices (Hawthorne et al., 2014).

1.5.5 Drama-based learning in science

Drama in education is of particular interest because of its qualities that engage with the familiar world. Drama pedagogies are based on narrative rather than argumentation, and seek to be evocative, using metaphors to embody concepts and ideas. In contrast with expository or argumentative discourse, the dominant communication modes in science, narrative has the ability to integrate disparate concepts and to draw on culturally familiar experiences and themes (Negrete & Lartigue 2004). A narrative follows a sequential pattern of events, rendering the content easier to follow (Avraamidou & Osborne, 2009).

Odegaard's (2003) review concluded that the key benefits of drama to science education were in the areas of higher level cognitive and affective learning. Drama-based approaches increased positive attitudes towards science (Abed, 2016) and intrinsic motivation (Kolovou & Ju Kim, 2020), as well as knowledge, compared to a non-drama control group. Many authors attributed the pedagogic advantage of drama to the positive affect generated by its interactive and creative qualities, as well as its use of 'real-world' situations (for example, Harper et al., 2019).

2. METHODOLOGY AND METHODS

2.1 Methodology

I embarked on this research as a biologist, encumbered with positivist ideas, and believing that my educational research should be based on the 'hypothetic-deductive' method (Gomm, 2017, pp. 213–240). My original research was based on a quantitative, pre/post design, with very limited elements of interpretivism. I rapidly began to discover that this approach limited my inquiry as it could not be used to study and explain causality very successfully, and so I increasingly employed qualitative methods that allowed me to develop my understanding of learner perceptions and experiences. As I matured into an educational researcher, my philosophical beliefs shifted to the paradigm of critical realism, as conceived by Maxwell and Mittapalli (2010, pp. 145–168), with interpretive influences (Mack 2010), although I have not as yet applied any naturalistic approaches (Carl & Ravitch, 2018, pp. 1135–1137).

Ontologically, I have grown to appreciate through my research that social reality is intrinsically subjective, because it is constructed by humans. In other words, many phenomena can be interpreted in different ways. I recognise that the hypothetic-deductive method in isolation does not allow us to reach an in-depth understanding of human behaviour and learning. Methodologically, I recognise that research design should be shaped by the nature of the inquiry and the needs of the research setting. In axiological terms (Creamer, 2017), I aspire to undertake research that informs educational practice, as described by Badger (2018, pp. 635–636) whilst attempting to capture some of the complexity of learning, particularly around multimodal approaches, engagement and positive affect.

I used a mixed methods design for all my studies, which Creamer (2017) defined as research which, as a minimum, includes both deductive and inductive elements (Figure 3 below). Quantitative approaches allow the researcher to study a sufficiently large population sample to generate inferences about the learner population as a whole and make credible recommendations for learning (breadth), whilst qualitative approaches delve into the mechanisms responsible for learning (depth).

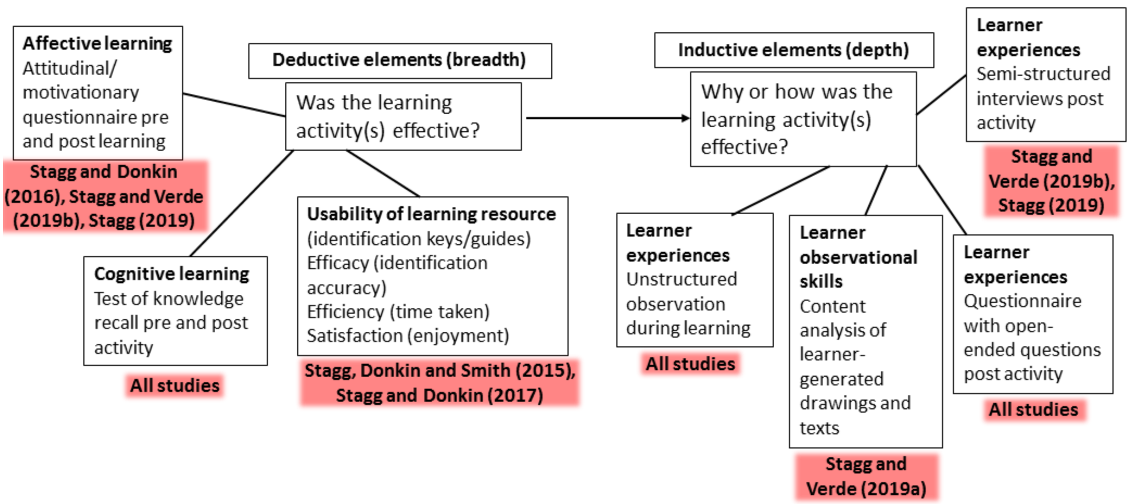

Figure 3. Summary of research methods in the thesis (red boxes indicate which studies used the adjacent method)

I undertook numerical data collection followed by statistical analysis, in most cases to test a hypothesis and draw inferences based on the hypothesis, a standard deductive approach (Gomm, 2017) I also collected data using open-ended written questions, which I transformed using a content analysis with no pre-existing categories, an inductive, emergent approach (Creamer, 2017). This aspect of the research design served to explore why and how learning had occurred, often producing insights or explanations that diverged from the original hypotheses or theoretical frameworks. In Stagg and Verde (2019b), for example, the analysis of interview and questionnaire data suggested that humour, music and novelty were more important for learning than the narrative qualities of drama that were examined in the theoretical section.

Later studies featured more qualitative methods than earlier studies, namely data collection using learner-generated drawings and texts, or interviews with learners combined with inductive analyses, generating a richer understanding of how the experience contributed to learning.

Earlier studies also tended to focus on intrinsic factors influencing learning (for example, design and content), whereas later studies focused on extrinsic factors (for example, the extent to which learning content was novel, humorous or participatory).

Creamer (2017) discussed the need to integrate the quantitative and qualitative approaches at different stages of the study in a mixed methods research design. In common with many mixed methods studies, mixing in my research occurred mainly at the discussion stage, where linkages were made between the inferences from qualitative and quantitative strands. Such studies are better described as partially integrated, or “multi-method”. In these earlier studies, the methodological emphasis was on quantitative approaches, with a greater balance and more convergence between quantitative and qualitative approaches emerging in my most recent three studies (Johnson, Onwuegbuzie, & Turner, 2007). In these three studies, mixing also occurred at the defining the research questions stage (interlinked qualitative and quantitative questions) and in the data analyses, where data from open-ended and closed questions were analysed together.

2.2 Methods and Instruments for the Research Studies

This section provides an overview of the methods used in my published studies. For each learning approach, I developed a practical, user-friendly example to trial in the classroom, evaluated its use and identified where it may be used to improve or build on existing practice (Gilbert, 2008).

I evaluated learning of plant identification and/or conceptual understanding of taxonomy using a pre- and post-test design (Table 5 below). I evaluated learner experience using questionnaires with open and closed questions. In drama studies, questionnaires included a suite of attitudinal questions using a Likert scale and semi-structured interviews with a sample of study participants. Thematic analysis was employed for qualitative interview and questionnaire data, using pre-determined and emergent coding respectively. Stagg and Verde (2019a) featured a content analysis of learner-generated drawings and written descriptions.

Adult participants (Table 6 below) were tertiary students enrolled, in most cases, on biology programmes and members of nature conservation organisations. Participants attended on a voluntary basis and sessions were held outside of scheduled teaching times for the tertiary students. Participants were recruited via event announcements to relevant programme leaders in Devon, specifying that events were targeted at people with little or no plant identification expertise. Occasionally, experts participated in events, as shown by pre-learning test scores, in which cases their data were excluded. Children attended primary schools and participated during lesson time. Schools were recruited via event announcements circulated to all head teachers and science subject leads in the county. Due to the intervals between each study, the likelihood of individuals participating in more than one was study was low.

All studies were based on direct experience with live plants, apart from Stagg and Verde (2019b) where the focus was on physical theatre and educational models. Focal plant taxa were determined by local availability, season and learning resource (Table 6 above). Native common species from habitats in or near the campus were used, as a way of promoting interest and attention for plants that learners encountered on a regular basis (Lindemann-Matthies, 2002). For the same reason, there was an emphasis on recognition skills that could be applied year-round, for example, identification of bryophytes and hardy perennial herbs using vegetative characters.

Methods	**Stagg and Donkin (2013)**	**Stagg et al. (2015)**	**Stagg and Donkin (2016)**	**Stagg and Donkin (2017)**	**Stagg and Verde (2019a)**	**Stagg and Verde (2019b)**	**Stagg (2019)**
Quantitative							
Test of cognitive learning pre- and post-intervention	x		x		x	x	x
Delayed test of cognitive learning					x (unpub.)	x	x
Test of cognitive learning during the intervention		x		x			
Test of affective learning pre- and post-intervention (attitudes or motivation)			x (unpub.)			x	x
Likert-scale or closed questions in post-learning questionnaires	x		x	x	x	x	x
Qualitative							
Learner-generated drawings and texts					x		
Open-ended questions in post-learning questionnaires	x	x	x	x	x	x	x
Semi-structured interviews						x	x
Unstructured observations	x	x	x	x	x	x	x

Table 5. Data collection methods used in studies ('unpub.' refers to data that were collected but not included in the final paper due to issues with data quality, e.g., sample size)

Key factors	Stagg, and Donkin (2013)	Stagg et al. (2015)	Stagg and Donkin (2016)	Stagg and Donkin (2017)	Stagg and Verde (2019a)	Stagg and Verde (2019b)	Stagg (2019)
Participants	Adults	Adults	Adults	Adults	Adults	Children	Children
Sample number	43	52	61	64	41	144	108
Duration (hours)	3.5	2	3.5	2	3.5	2	2.5
Pedagogic approaches	Mnemonics, word key, card game	Electronic and printed pictorial keys	Mnemonics, card games, pictorial keys	Field guides, mobile apps	Descriptive writing and drawing	Creative arts drama	Historic process drama
Focal plant taxa	Native trees, shrubs and herbs	Native bryophytes	Native herbs	Native herbs and trees	Native herbs	Exotics	Native herbs and exotics
Topic	Taxonomy	Taxonomy	Taxonomy	Taxonomy	Taxonomy	Reproduction	Classification

Table 6. Educational characteristics of studies

Potted specimens were used wherever possible to promote 'whole plant' recognition. Between 5–13 plant species were studied in each learning episode. Learners were trained in use of a hand lens (magnifying glasses with children) for close observation of specimens. Experimental trials were up to 3.5 hours long and were based in campus classrooms, with follow-up fieldwork in some studies. The brevity of the interventions was due to funding and volunteer availability constraints, and will have limited their scope for any durable changes in learning or attitudes.

2.3 Ethical Considerations

For all studies, subjects were required to complete and sign a consent form prior to participation (Appendix 2). The form explained what was required of participants, trial duration and content, how to withdraw from the study, data protection and data storage information. For studies with minors, parents and legal guardians were also sent an information sheet with this information and details of how to opt out (Appendix 3). Personal data was anonymised immediately after the study and destroyed, in accordance with institutional guidelines (Appendix 4). A consent form was also used for any photographing or video recording. All research studies were authorised by the Plymouth University Faculty of Science and Environment's Human Ethics Committee.

2.4 Data Quality

Validity, or authenticity, particularly in quantitative studies, refers to the extent to which experimental design, data and inferences are appropriate for the purposes of the study (Leung, 2015). Content validity was particularly important in the thesis research because the focal variables (cognitive and affective learning) could not be measured directly, thus knowledge tests and attitudinal questionnaires were used as proxy measures (Muijs, 2011, pp. 64–84).

I designed these instruments based on existing good practice to ensure validity, for example, in Stagg and Donkin (2019b), the evaluation questionnaire was developed from exemplars for school science in two high impact studies. Research instruments were piloted for most of the studies, to check if they measured the variables and dimensions intended and revised where required, for example several questionnaire items were reworded in Stagg (2019) because a majority of respondents opted for the 'not sure' category. Stagg and Donkin (2013) was, in effect, a pilot study for Stagg and Donkin (2016).

The application of multiple research methods in this research also contributed to the validity or trustworthiness of the results, through corroboration between data sources (also known as triangulation, see, Collins, 2017, pp. 280–292). Maxwell (2017, pp. 116–140) discussed how qualitative methods may improve the validity of questionnaire and test data by providing an insight into participants' perspectives. In Stagg (2019), for example, the attitudinal change identified in the questionnaire data converged with a dominant theme in the interview data, namely that respondents found plants more interesting due to an enhanced appreciation of plant diversity.

Reliability, again, particularly in quantitative studies, refers to the degree of accuracy or consistency in the methods applied (Leung, 2015). In the three 2019 studies, I involved two coders for thematic content analyses of the interview and questionnaire data to avoid the subjective interpretation of data, using Hayes and Krippendorff's (2007) alpha as a measure of inter-coder agreement. In drama studies, questionnaires contained multiple items for each construct and I verified internal consistency (homogeneity of response items) using a coefficient alpha (Muijs, 2011).

Generalisability refers to the extent to which results and inferences from the study sample can be extended to the intended population (Muijs, 2011). In quantitative research, generalisability is usually determined by whether a statistically significant causal relationship is identified in the sample and its magnitude (strength). In common with many educational studies, a challenge in the thesis research was that participants were selected using opportunity sampling, instead of randomisation (Cohen, Manion, & Morrison, 2007). Participants were randomly assigned to treatments where different interventions were directly compared, for example, Stagg and Donkin (2016). Another limitation was that studies did not include effect size in statistical reporting (Maxwell, 2017). The sample size in the thesis studies was reasonable: a mean of 73 participants, which exceeded the sample size in more than half of the educational studies reviewed. All studies, except Stagg at al. (2015), were replicated with multiple study groups and in multiple settings.

2.5 Methods for the Thesis Research

I conducted a narrative review based on thematic content analysis of the text–based, qualitative data (Neuendorf, 2019, pp. 211–223). I read through each study several times, to immerse myself in the content. I developed a set of themes based on my theoretical framework. I highlighted all text segments (factual items) relevant to the themes, using a colour-coding system, then aggregated segments (Appendix 5). A text segment was defined as a single factual item (Stemler, 2001).

During this process, I reviewed themes to see if they provided a good fit for the data (Appendix 5). I discarded the “compatible with learners’ cultures” theme due to insufficient data. I split content from the “embodied cognition” theme between “depth of processing” and “multimodal learning” because these themes captured the underlying processes in the former. I incorporated “usability” into “cognitive load” . I developed an analytical narrative for each of the revised set of themes, which formed the basis of the thesis discussion.

3. PUBLISHED STUDIES AND RESULTS

3.1 Published studies

Journal of Biological Education

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Teaching botanical identification to adults: experiences of the UK participatory science project 'Open Air Laboratories'

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Case study

Teaching botanical identification to adults: experiences of the UK participatory science project 'Open Air Laboratories'

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Taxonomic education and botany are increasingly neglected in schools and universities, leading to a 'missed generation' of adults that cannot identify organisms, especially plants. This study pilots three methods for teaching identification of native plant species to forty-three adults engaged in the participatory science project 'Open Air Laboratories' (OPAL). The three teaching methods (dichotomous key, word association exercise based on a mnemonic approach and pictorial card game) proved equally effective in teaching plant identification to participants for the groups of plants used. The dichotomous key is an established method for teaching transferrable identification skills, whilst the other two methods could be useful tools for stimulating initial interest and awareness in novices. The reasons for the decline in botanical knowledge are discussed, alongside the importance of using appealing identification resources and making botany relevant to people's lives.

Keywords: botany; botanical education; Open Air Laboratories (OPAL); plant identification; taxonomy; teaching methods

Introduction

The 'taxonomic illiteracy' of Western cultures has been recognised but limited research exists on the most effective methods for teaching species identification, especially in adults (Randler 2008; Balmford 2002; Lindemann-Mathies 2006). A recent House of Lords inquiry described the state of taxonomy and systematics in the UK as 'unsatisfactory' and a shortage of trained taxonomists, especially for less charismatic taxa, has resulted in a 'taxonomic impediment' to effectively monitoring and managing biodiversity (Boxshall and Self 2010; Convention on Biological Diversity 2012). Taxonomy is one of the science areas where 'citizen scientists' can most meaningfully participate but there is a need for more training in identification skills and novel training methods (Boxshall et al. 2011). Open Air Laboratories (OPAL), a partnership between English universities and conservation organisations, seeks to improve citizens' engagement in taxonomy and to engage local communities in learning about and monitoring their local environments (Davies et al. 2011). Botany has long been a neglected aspect of biological education in curricula, textbooks and courses from school to university level. The cycle is self-perpetuating, with biology teachers neglecting botany because of its absence in their own formative education (Hershey 1993, 1996, 2002; Drea 2011). In a study of A-level biology students, for example, 86% could recognise only three or fewer native plant species – which was not surprising, as their teachers' botanical identification skills were also poor (Bebbington 2005). Botanical education is an integral component of ecology, and the rapid loss of plant life and its implications for mankind deserves a more prominent role in education (Galbraith 2003; Sanders 2007).

This study pilots three teaching methods for the identification of native plants in a lifelong learning setting with young unemployed adults, university

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students and community members. Teaching methods are a language-based dichotomous key, a card game and a word association exercise, with fresh and dried plant specimens presented in groups of ten, as an optimal number of species to memorise per trial (Randler and Bogner 2002). The language-based dichotomous key was included as the most common method of learning plant identification, requisite in many school and undergraduate syllabi (Randler 2008). Black and white keys have the advantage of being reproducible at low cost and the language-based mode encourages the student to scrutinise specimens in more detail (Randler 2008). The keys were designed for complete beginners, with no technical terms used and a small number of line drawings where necessary to illustrate terms (Ohkawa 2000). The word association exercise was based on the mnemonic (memory-enhancing) approach used successfully in Carney and Levin (2003) for memorising fish species and in Rosenheck et al. (1989) for memorising the classification of angiosperms. The pictorial card game approach has been successfully used for promoting the learning of satellites, chemical elements and formulae, but not for species identification (Sevcik et al. 2008; Smith and Munro 2009; Morris 2011).

Methods

A total of six groups participated in half-day events organised by OPAL at indoor venues in Plymouth and South Devon from November 2009 to April 2011. Of these groups, three (Gloucestershire BTCV, Torbay BTCV and Plymouth Foundation for Learning) were required to attend the sessions as part of employment benefits schemes contracted to nature conservation organisations, and all twenty-four participants were male. The other three events were attended by nineteen volunteer students and local residents of both sexes. The OPAL Community Scientist, an experienced educator, was responsible for all event delivery. A pilot event took place in October 2009 with conservation group BTCV Plymouth but the data were not used, as the methodology was reviewed and improved following the event.

Each event comprised three thirty-minute sessions that taught the identification of ten plants, with the order of sessions as follows: dichotomous key using fresh or partially fresh winter twigs from trees; word association exercise using potted common weeds; and pictorial card games using dried seed heads of hedgerow plants. Species lists for the three plant groups are shown in Table 1. Limited availability of suitable plant material prevented the three teaching methods and plant groups being interchanged.

Participants completed a written identification test on the ten plants prior to learning (1 mark per complete plant name, 0.5 marks for half the name), which was repeated after learning, following a short distraction break for refreshments and unrelated discussion. The participants completed a brief socio-economic questionnaire and evaluation form. Statistical analyses used PASW Statistics 18.

The dichotomous keys were specific to each plant group and avoided the use of technical terms. In the word association exercise, participants developed memorable prompts linked to the species' name and visual characters, such as 'fluffy, to tickle the travellers with' for traveller's joy, 'pointy buds that make you screech' for beech (because of the sharpness of the buds when touched) and 'teasing a kitten with a hair brush' for teasel. The card games used a 'deck' of fifty-two cards featuring close-up colour photographs of the ten species (Figure 1). The participants played games of rummy (matching the visual characters or name similarities of the cards) and snap. The OPAL Community Scientist led a nature walk after the teaching sessions, when time and weather permitted, to teach field identification of the focal species and embed classroom learning.

Socio-economic profile of participants

Figure 2 indicates that participants were predominantly male (62%) and predominantly aged between

Table 1. Species lists for plant groups

Dichotomous key – winter twigs of trees	Word associations - seed heads of hedgerow plants	Card games – common weeds
Oak	Selfheal	Bittercress
Hazel	Hawthorn	Campion
Lime	Sloe	Heartsease
Ash	Dock	Moon Daisy
Sycamore	Beech	Spear Thistle
Alder	Travellers Joy	Pennywort
Horse chestnut	Ash	Common Mallow
Dog rose	Teasel	Willowherb
Birch	Spindle	Yarrow
Beech	Gladdon	Ribwort Plantain

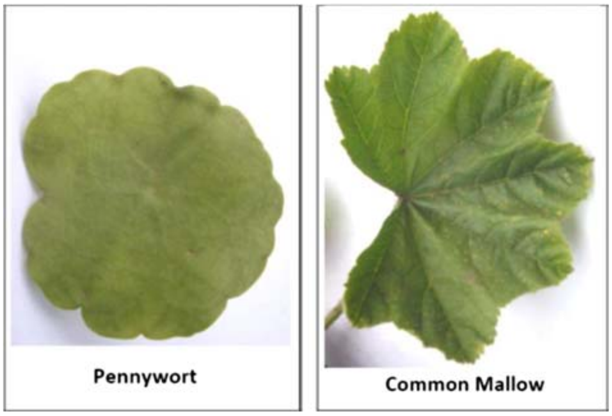

Figure 1. Sample playing cards

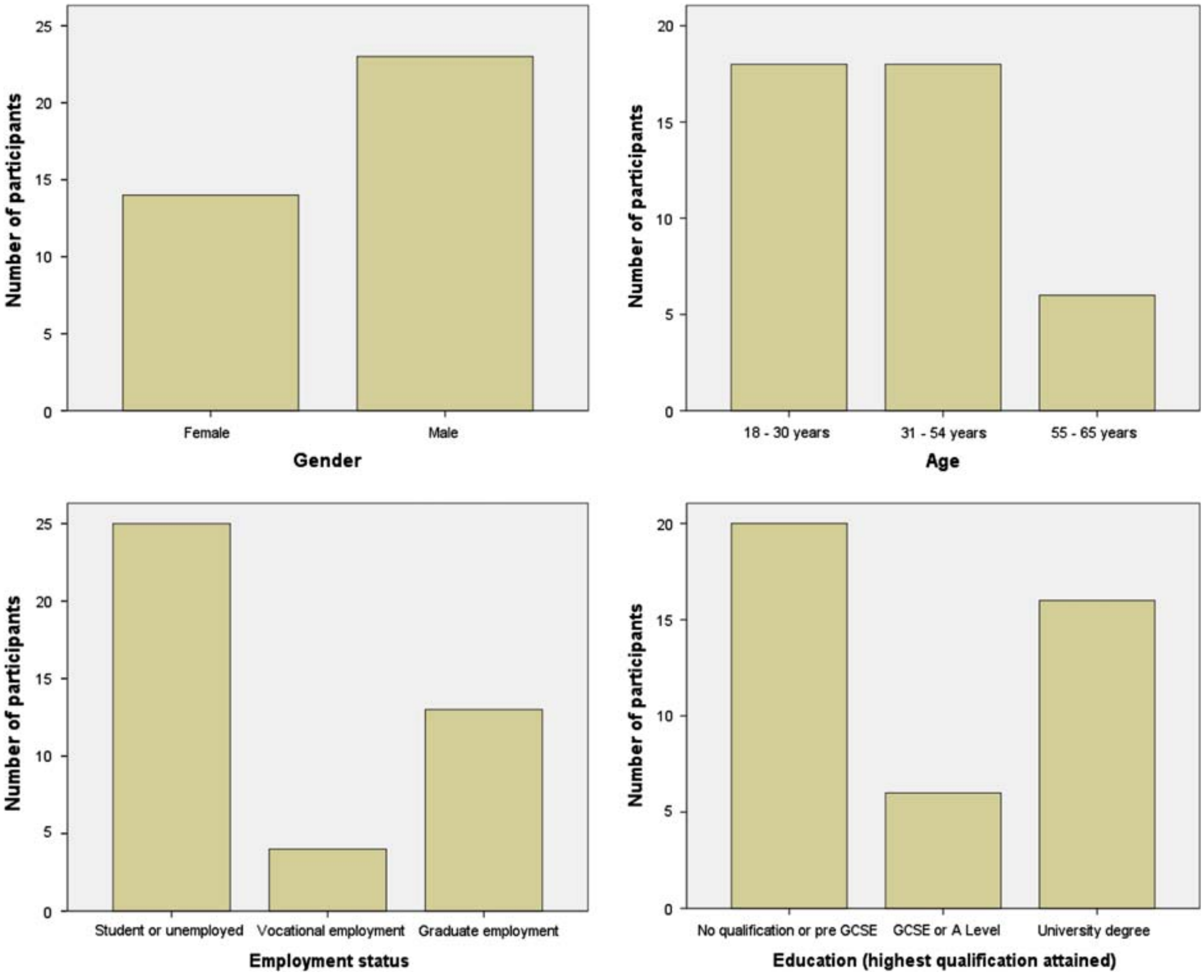

Figure 2. Socio-economic profiles of study group

either eighteen and thirty (42%) or thirty-one and fifty-four (42%). The majority of participants were unemployed and had no qualifications, followed closely by university students.

Results of plant identification tests

The mean average for test score pre-learning was 1.95 for winter-twig tree species, 2.71 for hedgerow seed head species and 1.35 for weed species. A Wilcoxon Signed Ranks Test identified a significant difference between the medians of test score pre-learning and post-learning for all three teaching sessions (p = 00001 in each case).

A Generalised Linear Model with gamma distribution was fitted to the distribution of test scores post-learning, using the input variables presented in Figure 2, test score pre-learning as the co-variate and relevant interaction terms. Gamma distribution was used because the dependent variable test score post-learning did not fit a normal distribution.

Table 2. Test of Model Effects using a Wald Chi-Square

Tests of model effects			
	Type III		
Source	Wald Chi-Square	Degrees of freedom	probability
(Intercept)	678.333	1	<0.0001
Education	31.446	3	<0.0001
Test result prior to learning	10.303	1	0.001

Input variables: age; education; employment status; gender; teaching method
Covariate: Test result prior to learning
Dependent variable: test result 'post learning'

Non-significant terms were removed systematically, leaving education and the co-variate test score pre-learning (Table 2). Figure 3 shows the effects of educational category on mean number of species identified before and after learning overall, whilst Figure 4 shows the effects specific to teaching method. For the combination of teaching methods and plant groups used in the study, participants with higher educational attainment are able to recognise more species both before and after the teaching session than participants with lower educational attainment.

Participants' experience

Poor literacy may have affected test results in some cases: for example, a number of Foundation for Learning participants wrote 'spe' for 'spindle' and 'bee' for beech, inferring that they could recognise the species but did not know how to write it. Common misidentifications in all groups were dogwood for lime, thistle for blackthorn (or hawthorn) and geranium for mallow. Evaluation forms were completed by twenty-seven participants; twenty rated their enjoyment of the event at 8/10 or above (Figure 5). Written comments on the forms included: 'especially enjoyed the word associations when they were ridiculous and funny'; 'all these methods worked well for me'; 'makes plant identification seem less overwhelming and I can see how to build my plant knowledge bit by bit'; 'I've never done anything like this before and learnt a lot'; 'would recommend to others'. Suggestions for improvement included: 'it's easier to remember a plant when you know its practical use'; 'species with two words were harder to remember than single words' and 'games help me to learn but I'd improve the games'. A total of four participants commented that they would like to have learned more about the plants, for example the plant families and overall appearance of the plant, and several participants commented that they would have liked fresher specimens for the winter twigs and seed heads. The nature walks were infrequent due to bad weather but were generally enjoyed, and several participants reported greater confidence and improved species recognition as a result.

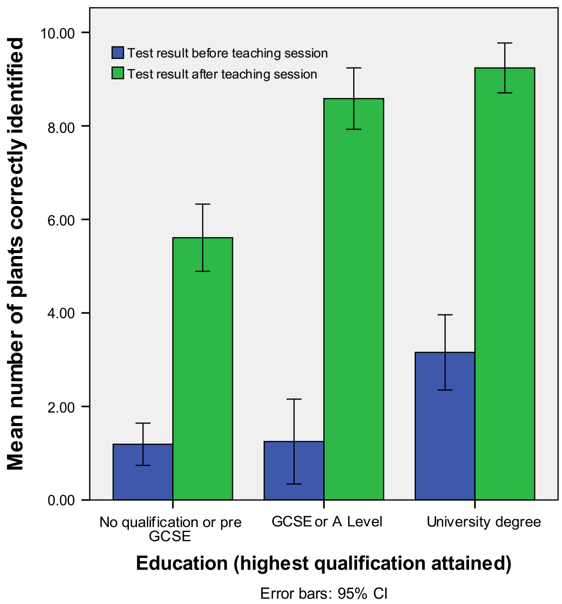

Figure 3. The effect of educational category on plant species identification

Discussion

Recognition of plant species prior to teaching sessions was low, reaffirming concerns about taxonomic illiteracy expressed in the literature on the subject. The significant difference between test scores prior to and post-learning suggests that all three teaching methods were effective for the plant groups used in spite of a large proportion of the target audience having no experience of taxonomy or possessing formal qualifications. Participants with higher qualification attainments learned the names of significantly more plants than those with low qualification attainments, perhaps because they have more familiarity or confidence with plant identification or memory tasks.

These preliminary results suggest that the long-established dichotomous key method is as effective as the card-game and word-association methods. The dichotomous key teaches participants identification skills that can be transferred to other plant species, whereas the card game and word association methods promote plant recognition without inferring identification skills. Their value, therefore, is for raising awareness and engaging students, alongside use of a dichotomous key exercise as the primary learning tool. Observations of body language and verbal reactions suggested that these participants found the informal game-orientated approaches less intimidating than the problem-solving exercise, which was perhaps reminiscent of a school environment. The dichotomous key in this study was based on the test

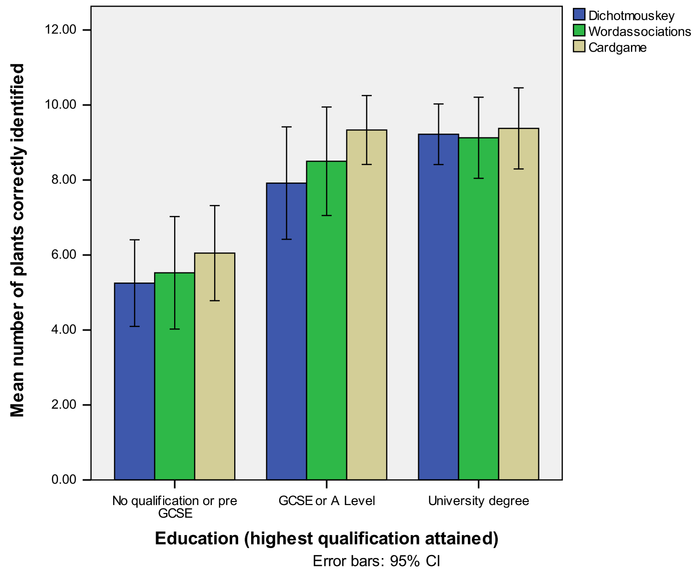

Figure 4. Comparison of plant identification results following three teaching methods for different educational categories

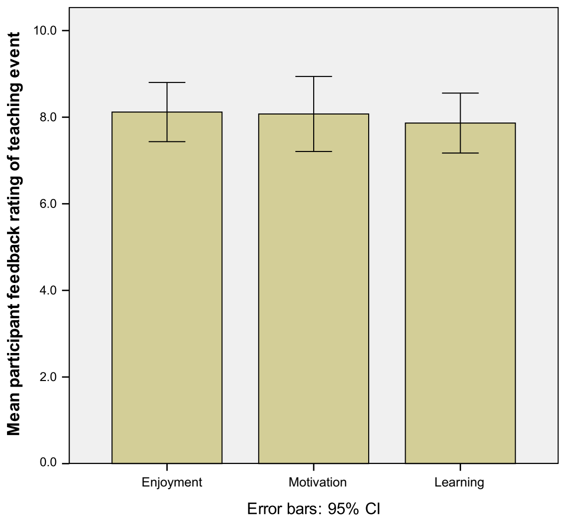

Figure 5. Feedback from 27 participants on the OPAL botanical identification event

plants alone and used no technical terms, which improves motivation compared to conventional keys (Ohkawa 2000; Silva 2010). Both the dichotomous-key and word-association methods promote exploration of the live plant specimen and morphological characteristics, whereas the card game focuses on superficial appearance, making it a less valuable taxonomic learning tool. The word-association method required the most verbal instruction and teacher-led discussion, which Randler and Bogner (2002) found less effective than 'hands-on' interactive approaches with school students.

The participants in this study were able to learn to recognise plant species effectively whilst enjoying the experience, refuting the concept of 'plant blindness' proposed by Wandersee and Schussler (1999), which infers that people are inherently less interested in plants than in animals. A number of studies propose that the demise in botanical interest is in fact due to the way botany is taught (if it is taught at all) and presented in the world at large. Schussler and Olzak (2008) describe biology teachers as 'zoochauvinistic' and found that undergraduate students could identify only 65% of a sample of common flower species, compared to 92% of animal species. In the life-sciences sections of two popular US undergraduate textbooks, photos of animals were more numerous and diverse than those of plants, as well as being three times more likely to be labelled by species, with plants labelled by plant part or life form (Perez et al. 2007). Uno (1994) identified that plant biology features in less than 20% of high-school biology courses. Plants rarely feature in popular science media or in cartoons, films and games (Hershey 2002). They are portrayed as passive organisms, inferior to animals because they appear to be unable to react to stimuli and defend themselves (Nantawanit 2011). The popularity of the imaginary plant species in Pokémon games could be a consequence of their combative and active behaviour (Sanders 2007). Cultures dependent on their environment for their livelihood tend to have good plant identification knowledge, which is lost when the population becomes 'Westernised' (Schussler and Olzak 2008). This suggests that taxonomic ignorance can be partly attributed to a lack of relevance of plants to people's lives rather than a disconnection from plants *per se*. Richards and Lee (2002) highlight the importance of practical and personal experience of plants in undergraduate botanical education and the University of Oklahoma discovered that the number of botany majors increased from eleven to forty when they shifted the course's focus to applied topics (Uno 1994). The solution, therefore, lies in highlighting the relevance of plants to people's daily lives and using appealing media that reform the image of botany or taxonomy as dull and outmoded (Hershey

Figure 6. (Clockwise from bottom left): collecting *Urtica dioica* for textile dyeing; weaving *Salix* and *Cornus* species; 'wild food' foraging; hanging balls woven from *Ilex aquifolium* at a public event

2002). The author, Bethan Stagg, organised a series of 'plants and people' events for OPAL in 2008–2010, including wild food walks, wild plant pigment painting, textile dyeing and hedgerow basketry. Events were popular with people of different ages and backgrounds and appeared to elicit a positive attitude to plants (Figure 6).

This preliminary study piloted three simple teaching methods in a lifelong learning context, as a precursor to future studies. A valuable further line of enquiry would be to test the language-based black and white keys used in this study against full-colour picture-based keys, similar to those produced by Kirchhoff et al. (2010) or by the Field Studies Council for the OPAL National Surveys (Open Air Laboratories 2012). Picture-based keys have been proven to be effective in a number of studies mentioned in this paper and could be particularly useful for literacy-limited groups such as those involved in this study. Another useful area of study would be testing the traditional dichotomous keys, which are based on a series of steps with two choices each time, against 'multi-access' keys like those explored in Ohkawa (2000) and Silva et al. (2010) or the Bayesian keys recently developed by the Open University for OPAL for mobile electronic devices (Open Air Laboratories 2012). Future studies will use better-quality fresh specimens, as requested by participants in the feedback in this study, and teaching methods and plant groups will be presented in a randomised order, as used by Randler (2008).

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Bryophytes for Beginners: The usability of a printed dichotomous key versus a multi-access computer-based key for bryophyte identification

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Bryophytes for Beginners: The usability of a printed dichotomous key versus a multi-access computer-based key for bryophyte identification

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Bryophytes are a rewarding study group in field biology and the UK bryophyte flora has international importance to biodiversity conservation. We designed an identification key to common woodland moss species and compared the usability of two formats, web-based multi-access and printed dichotomous key, with undergraduate students. The rate of correct species identification and identification speed both showed an advantage for the printed dichotomous key. Our findings suggest that, even in the digital age, printed keys remain valuable in biological education and that quality of key design is more important than presentation medium. We discuss the relative advantages of multi-access and dichotomous keys and how to approach bryophyte identification with beginners.

Keywords: *Botany; Bryophytes; Identification Keys; Digital Technology; Multi-access Keys; Dichotomous Keys*

Introduction

Bryophytes (mosses, liverworts and hornworts) are primitive terrestrial plants which reproduce mainly by spores (Watson 1981). Two thirds of UK bryophytes are mosses, which have erect or creeping stems, tiny leaves and filamentous threads called rhizoids, in lieu of roots. Bryophytes require moist conditions which explains why Britain and Ireland have a particularly rich bryophyte flora (two thirds of all European species, compared to just a sixth of Europe's angiosperms and ferns) (Atherton, Bosanquet, and Lawley 2010). The UK bryophyte flora is of global significance but more than 10% of the 1100 species are threatened and listed on the UK Biodiversity Action Plan (Woods

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and Coppins 2012). Bryophytes play a major ecological role in a range of habitats; they are established biological indicators of environmental change and a key feature in the National Vegetation Classification (Grace 1995; Crawford 2002). An introduction to bryophyte identification is therefore a valuable skill for our future ecologists.

Bryophytes are an ideal study group for field biology since they are easily found in all seasons, including the winter when most potential study organisms are scarce (Atherton, Bosanquet, and Lawley 2010). Even the most unpromising school or campus grounds will have brick walls, concrete surfaces or roof tiles studded with the neat cushions of *Grimmia pulvinata* (hedgehog moss), or *Tortula muralis* (wall screw-moss), whilst established urban woodlands may yield several species. Tuition in plant identification is proven to be most effective when live specimens are used (Taraban et al. 2004; Teolis, Peffley, and Wester 2007; Stagg and Donkin 2013). Bryophytes are compact and easily stored live for several weeks in a shaded, frost-proof environment, or dried as herbarium specimens, since species resume their natural form and appearance once wetted (Atherton, Bosanquet, and Lawley 2010).

The reasons why bryophytes are not a more common choice for field study include their small size, absence of flowers, underused common names, and the fact that biology teachers steer away from unfamiliar study groups (Grace 1995; Newberry 2004). Many bryophyte species show high intra-species variation according to microhabitat. This is an additional challenge for the biology teacher but may inform students on the influence of environment on plant habit. Until recently, bryophyte identification guides that are accessible to beginners were scarce, compared to other taxonomic groups. We now have the photographic field guide to woodland bryophytes produced by Crawford (2002), the British Bryological Society's field identification guide (Atherton, Bosanquet, and Lawley 2010), and the Open Air Laboratories' (OPAL) photographic key to orchard bryophytes (Stevenson 2013). These high quality identification keys and guides could prove to be valuable ambassadors for bryophyte conservation.

Lawrence and Hawthorne (2006) define usability of an identification guide using three parameters: effectiveness (enables user to make a positive identification); efficiency (minimises time and effort required from user); satisfaction (enjoyment from using the guide). Usability is determined by the navigability of the key, ease of understanding of the terminology and pictorial information (photos, illustrations, symbols), and ease of location and recognition of differentiation cues in the focal specimens. Keys for non-experts should not be unnecessarily simplistic or un-technical, since such measures would reduce their educational benefit, whilst keys that are enjoyable to use are proven to be more effective (Guarino, Menegoni, and Pignatti 2010; Stagg and Donkin 2013). Most printed identification keys are dichotomous keys, where each step in the key presents a choice with two alternatives (Dallwitz, Paine and Zurcher 2013; Drinkwater 2009). Electronic keys are usually multi-access, meaning that the sequence of steps is not fixed in a particular order. The user selects a value from a list of characters for each step and may skip or return to particular steps as they choose.

This study compares the usability of an electronic multi-access key with that of a printed dichotomous key for the identification of bryophyte species common in acid woodlands. Both keys in this study were produced by the lead author as a demonstration of what an educational professional without specialist IT or design skills is able to produce. Designing keys requires a high initial investment but allows the key to be tailored to curricular content and personalised to local environments, increasing their relevance to students' lives (Martellos 2010a). Key effectiveness was assessed using the rate of positive identifications in a keying-out activity of twelve species. Key efficiency was defined as the completion time for the keying-out activity. Key satisfaction was assessed with a 'post activity' self-reported evaluation.

Few studies in the literature have tested the usability of an electronic multi-access key alongside a comparable printed dichotomous key. Morse, Tardivel and Spicer (1996) compared a multi-access key with printed dichotomous key for woodlice identification and found no difference in student accuracy. A number of articles have discussed educational benefits of electronic keys and good practice in key design, without testing specific keys (e.g. Farr 2006; Martellos 2010b; Dallwitz, Paine, and Zurcher 2013). Others have examined issues in computer-based biodiversity education (Taraban et al. 2004; Teolis, Peffley, and Wester 2007; Ruchter, Klar, and Geiger 2010).

Keys in this study omitted spore capsule characteristics to allow for year-round use and because spore capsules become easily detached and lost from specimens that are stored and frequently handled. The keys were based on morphological characters discernible with the naked eye, therefore excluding leaf margin and central nerve characteristics. In the authors' experience as botany tutors, students have difficulty relying on finer details until they are confident using a hand lens. The first step in both keys requires differentiation between the two main growth types: pleurocarps, which are branched, sprawling species with scale-like leaves, and acrocarps, erect, upright species with infrequent branching and large, visible leaves.

Method

Identification Keys

Photographs of fresh specimens were taken in the laboratory using a Canon EOS SLR camera, with specimens displayed on a white background to assist differentiation (Leggett and Kirchoff 2011). Keys were produced using character data derived from multiple specimens, as recommended by Atherton, Bosanquet and Lawley (2010) and Crawford (2002). The printed key was produced using Microsoft Office PowerPoint 2007 and printed as a cropped A3 document on a colour Kodak photocopier (Figure 1). The key format was inspired by the OPAL key to common British earthworms, written by Jones and Lowe (2008) and designed by FSC Publications. Like Goulder and Scott (2006), the authors have found the Field Studies Council's fold-out laminated charts to be invaluable for introducing novices to species identification.

The electronic key was produced using the software and website of iSpot, which was developed by the Open University for Open Air Laboratories and funded by the Big Lottery Fund (iSpot, 2013). The key is viewable at http://www.ispotnature.org/uk-and-ireland. The key interface presents a list of characters and the user selects a character state for each one, in their preferred order (Figure 2). Users are able to review and modify their choice of character states during identification. A row of ticks accumulates next to the one or more species that closely match the user's selections. The user selects a

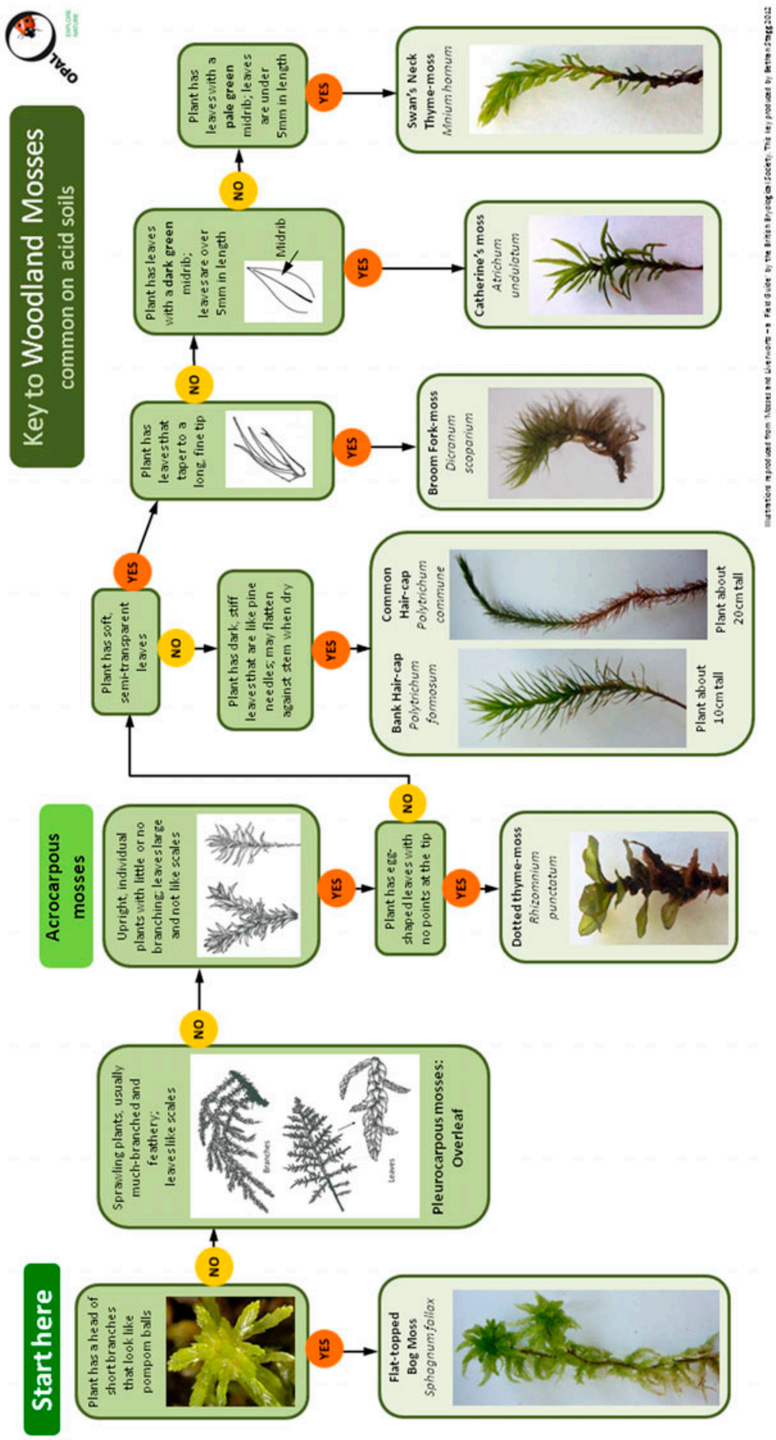

Figure 1. Front page of double-sided printed key produced for the study

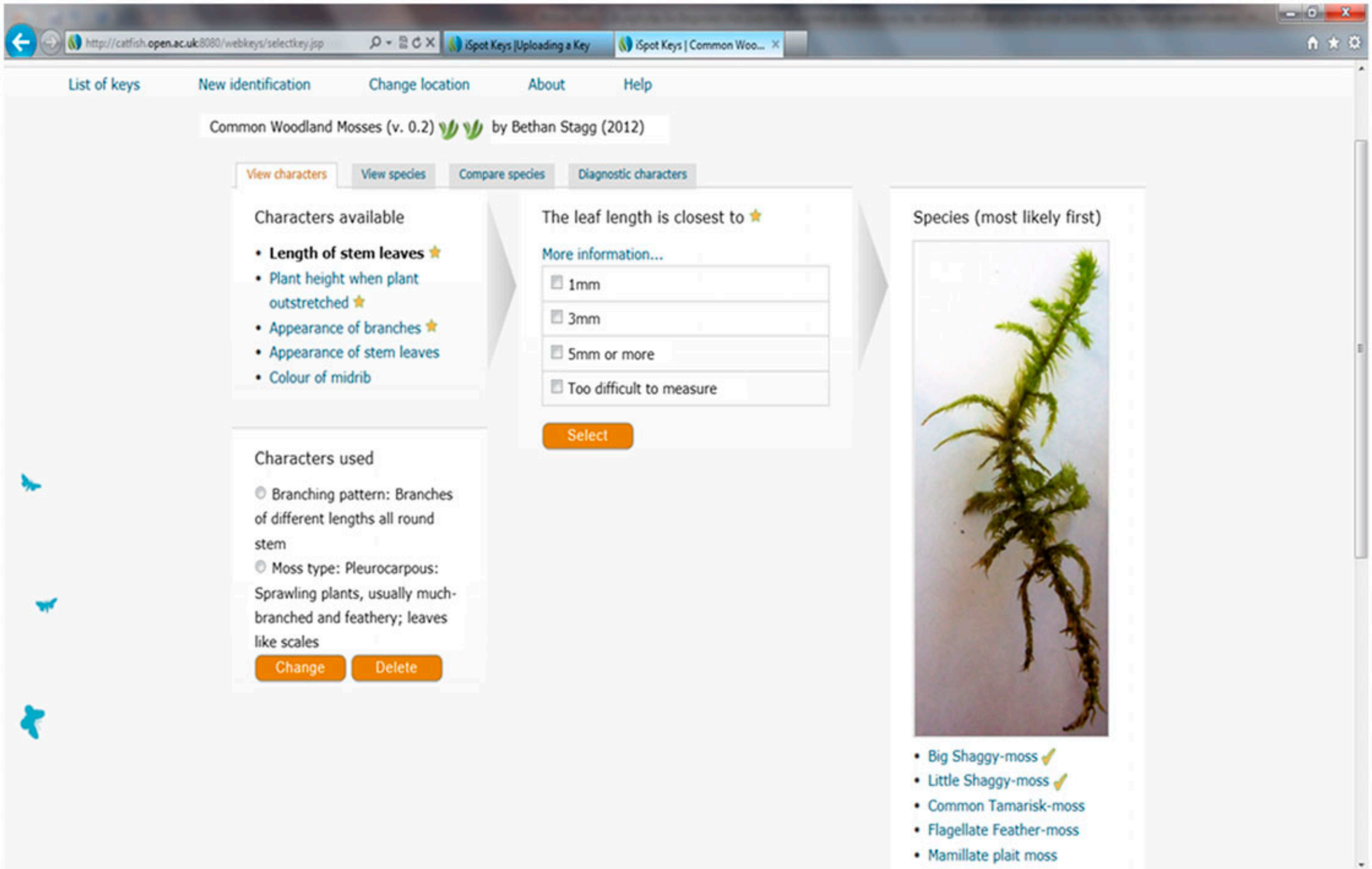

Figure 2. Example page from the electronic key, showing tick and star icons that guide user to a positive identification

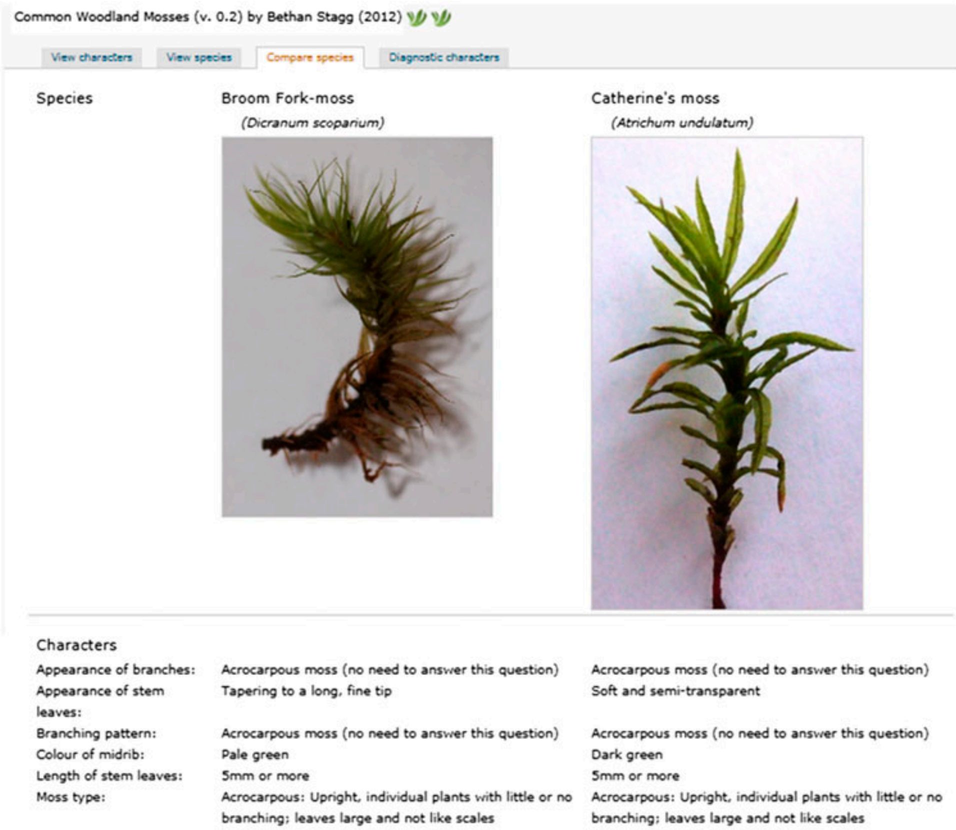

Figure 3. Example page from the electronic key, showing options for species comparisons

species and its photograph and list of character states is displayed, as well as a link to photographs uploaded by the iSpot user community. Users are able to compare similar species to verify identification (Figure 3). The iSpot key interface fulfils the recommendations for electronic key design in Farr (2006).

iSpot keys are based on a data matrix of species x character combinations saved in an Excel spreadsheet. Keys based on a matrix spreadsheet are less daunting for educators as there is no need to learn a new application (Hagedorn, Rambold, and Martellos 2010). Each species is required to have a unique set of character states for the key to function but the character matrix allows for some redundancy which contributes to key efficiency (Edwards 2010). Characters can be weighted according to their importance in determining a positive identification. In our key, moss growth type (pleurocarp or acrocarp) was allocated a 15% higher weighting than the other eight characters. It is also possible to have more than one correct answer for a species character state, which accommodates some of the intra-species variation that users will encounter. In our key, for example, a correct answer was registered if ‘predominantly pinnate’ or ‘short branches of different lengths around stem’ was selected for ‘branching pattern in *Rhytidiadelphus loreus*.’

Six university biology lecturers and technicians tested the two keys in November 2012 and the keys were revised based on their feedback.

Materials

Bryophyte samples were collected from woodlands in Buckfastleigh, Devon, in December 2012 and stored in sealed containers in a refrigerator. Fresh specimens were used for each identification session wherever possible and presented in Petri dishes to reduce moisture loss when not in use. Specimens were wetted with a dropper bottle during the session if required.

Experimental Procedure

Five identification sessions were held during December 2012 and January 2013, instructed by the OPAL community scientist, who is one of the authors. Fifty-two people attended these optional sessions: 20 Duchy College horticulture diploma students and 32 from Plymouth University (predominantly biological or environmental science degree students, with a few PhD students, interns and technicians also attending). Students were randomly assigned to desks with or without a computer on arrival. On each desk was a closed box containing 12 fresh bryophyte specimens in numbered Petri dishes, an instruction sheet, worksheets, hand lens (x10), ruler, and (in the case of students at desks without computers) the printed identification key. Students received verbal instruction on the keys, how to use a hand lens, and the rudiments of bryophyte anatomy, supplemented by an annotated handout. Students were required to complete the identification activity without conferring and to record identifications, start time, and finish time on a worksheet. The session culminated with instruction and feedback on identification of the focal species, followed by a self-reported evaluation. The evaluation form required the student to give the key a score out of ten for 'enjoyment and usefulness' and complete an open question on what they thought of the key. An independent-samples Mann-Whitney U Test was used to test the null hypotheses that there was no difference in number of species correctly identified (key effectiveness), time required to complete key (key efficiency) and enjoyment-feedback score (key satisfaction) using electronic and printed keys. This statistical test was chosen because one of the variables (key satisfaction) violated parametric test assumptions. All statistical analyses were produced using SPSS 21.

Results

Twenty-four students completed the electronic key and 28 students completed the printed key. None of the students were able to identify any specimens prior to the identification trial which is unsurprising as bryophyte identification was not a part of their curriculum. An independent samples Mann-Whitney U test identified significant differences at the 1% confidence level between both the number of species identified and the time required to complete the identification activity using the electronic and printed keys (Table 1). Students using the electronic key identified less species correctly and required more time

Table 1. A comparison of key effectiveness, efficiency and satisfaction for electronic and printed bryophyte keys. All calculations are shown to three decimal places

		Electronic key			Printed key			
Key characteristic	Variable	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size	P value in statistical tests*
Key effectiveness	Number of species correctly identified	8.271	1.950	24	9.768	1.624	28	0.007**
Key efficiency	Time (min.) to complete identification exercise	45.400	12.588	20	22.833	9.823	24	<0.001**
Key satisfaction	Feedback score/10 for key enjoyment	7.044	2.246	23	7.304	1.812	28	0.523

*An independent-samples Mann-Whitney U Test was used to test null hypotheses that there was no difference between electronic and printed keys for the three variables described.

**Denotes comparisons where there is a statistically significant difference at the 1% confidence level.

to complete the key, compared to the printed key. There was no difference in key satisfaction between the two key types.

Qualitative Feedback

Forty-five students completed written feedback (21 students for the electronic key and 24 for the printed key). Nine students described the printed key as being 'easy to use', with four students making the same comment for the electronic key. Three students described the key as 'very useful' for both keys. Eight students commented that: 'some descriptions of/distinctions between characters were unclear' for the printed key, whilst five students made the same comment for the electronic key. Other common comments for the printed key included: 'Pictures/photos were helpful/useful' (three students); 'pictures were confusing when the specimens looked different from the picture' (three students).

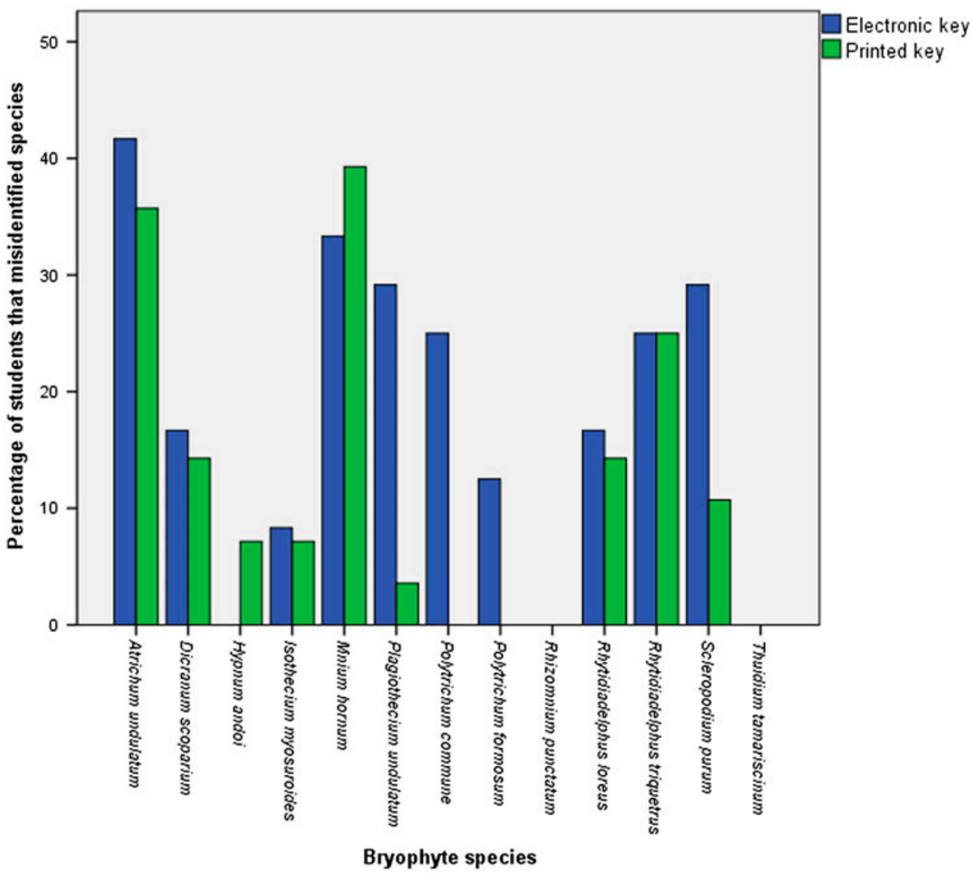

Figure 4. A comparison of species misidentifications for two key types for electronic and printed bryophyte keys

Relative Difficulty in Species Identification

Mnium hornum and *Atrichum undulatum* were the most commonly misidentified species for both keys, although in the authors' experience students do not normally have difficulty differentiating these species in the field (Figure 4). Confounding characters for these two species appeared to be the colour of the central nerve and leaf shape. Misidentifications were also high for the two *Rhytidadelphus* species which were most commonly misidentified for each other. Students were probably relying on plant height, which is similar for the two species, instead of comparing stem leaf lengths as instructed in the key. Misidentification was high for *Scleropodium purum* in the computer key, which was most frequently misidentified for the similar-shaped *Hyocomium armoricum*. The higher accuracy for this species in the printed key could be due to the easier comparisons allowed by this format, whereas the electronic key relies on the user selecting the correct species for comparison. Misidentification was high for *Plagiothecium undulatum* in the computer key. It was frequently mistaken as an acrocarp due to its large leaves and sparsely branched habit.

Discussion

A Comparison of the Electronic and Printed Keys

Key efficiency was higher for the printed dichotomous key, with the keying-out exercise taking about half the time to complete compared to the electronic multi-access key. As discussed by Hagedorn, Rambold, and Martellos (2010) and Krasna (2010), dichotomous keys require fewer decisions and character identifications than multi-access keys. The electronic key required physical navigation of up to sixteen mouse clicks and three page scrolling movements per species, which may also influence identification speed. Navigation is self-explanatory in the dichotomous key on account of the printed flowchart design, whereas navigation in the multi-access key relies on familiarisation and practice. Students had also probably experienced printed keys in other contexts and were familiar with their use, whereas they may not have used an electronic key before. Randler and Birtle (2008) demonstrated that students' performance with an unfamiliar key was improved if they were first acclimatised using a key based on a familiar group of species or objects as this reduces the cognitive load associated with key use.

Key accuracy was also higher for the dichotomous key, which had 81% correct answers for all identifications compared to 69% for the multi-access key. This result is surprising since multi-access keys allow for positive identifications even if a few characters are omitted or misclassified, making them more accommodating of novices' lack of expertise or disparity in a specimen's characters due to lifecycle or intra-specific variation (Farr 2006; Dallwitz, Paine, and Zurcher 2013). The benefits of such an effect, however, are probably more pronounced in keys with a higher number of characters and species than the key used in this study. Higher accuracy in the printed key is probably a consequence of its presentation format, which allows easy viewing of similar species and differentiating characters. Again, if students have used printed keys before their confidence with this type of key may contribute to the rate of positive identifications. The time consuming nature of the computer key may contribute to lower accuracy through diminished user motivation and attention. Students that took a long time to complete the electronic key were often observed in the latter part of the sessions to rely on comparisons between photographs and specimens instead of on character selections.

In the multi-access key the user is presented with a list of between three and six character states per character. This is more information to process at each step than in the dichotomous key and might increase the likelihood of mistakes. Common errors were students answering the questions that said 'pleurocarp only' for acrocarps, and vice versa, and misinterpretation of the illustrations in 'branching pattern.' Such errors may change the configuration of 'tick' icons so that incorrect species move into the shortlist of likely species, leading the user astray. To prevent this, some key designs incorporate character dependencies such that certain character values make other characters inapplicable (Dallwitz, Paine, and Zurcher 2013). An improvement in key design would be separate keys for pleurocarps and acrocarps, which the user was signposted to once answering the 'moss type' character state. 'Branching pattern' was also a problematic character for students, which is encountered at an earlier stage in the multi-access key (if the characters are tackled in the order in which they are displayed).

Key satisfaction was similar for the two keys, suggesting that the lower efficiency and accuracy did not detract from enjoyment for the electronic key. The electronic key allowed users to link to photographs of species in the field uploaded by the iSpot community but image quality was variable. Links to resources and user communities enhance user enjoyment, although some teachers found that such resources distracted from the identification activity (Tarkus, Maxl and Kittl 2010). The most common criticisms of both keys in written feedback related to difficulty understanding some character descriptions or using them in differentiation. For example, the character 'colour of midrib' for acrocarps (pale green or dark green) would have benefited from the inclusion of colour bands for comparison.

Digital learning resources are considered the natural choice for the current generation of students, who may tend to perceive printed resources as archaic. Electronic keys do not have the spatial constraints of a printed resource, allowing for enhanced information provision, and colour images and updates are incorporated without the costs associated with hard copy (Farr 2006). A range of tablets and other mobile devices allow for electronic identification in the field. iSpot have produced fourteen identification keys for mobile devices, including lichens, woodlice and ladybirds (www.ispot.org.uk/mobile keys). The number of iPod species identification apps applicable to the UK now exceeds twenty, eight of which are trees or wildflowers (https://www.apple.com/uk/itunes/). A small number of identification apps are also available for Android phones (https://play.google.com/store/apps). Apps have the advantage that they can be used in a stand-alone mode, once stored in the device's memory, making them easy to use in field localities (Martellos 2010a). In an educational context however, digital learning is often constrained by a lack of sufficient hardware for an entire student cohort, its durability at the hands of multiple users, and the speed at which hardware and applications become outmoded (Tarkus 2010). The authors relied on computers for testing the electronic key in this study because a set of personal digital assistants (PDAs) purchased by the university less than two years previously were already obsolete.

In a study comparing the efficacy of printed guidebooks, mobile devices, and oral guides as teaching media in a guided nature tour, knowledge retention and user satisfaction were similar overall for all three media. However, factors such as educational background did lead to differences in preferences between user groups (Ruchter, Klar, and Geiger 2010). This study argues for the value of using multiple media types in education to accommodate different learning audiences. A good example is the lichen identification key produced by Dryades, which is available for computer, mobile device, and as a printable field guide (Nimis, Wolseley and Martellos 2009).

Tailored Identification Keys

Learning biodiversity specific to locality and relevant to learners' lives is an effective way of improving intrinsic motivation (motivation driven by an interest or enjoyment in the task itself), as well as developing stronger nature connections (Lindemann-Matthies 2002; Jakel, 2013). By tailoring a key to locality, the students encounter and differentiate a manageable number of species, an important element of biodiversity learning (Randler and Birtle 2008; Goulder and Scott 2006; Jakel 2013). An inquiry-based learning approach, where it is the students that research and produce the key as part of the module coursework, is another approach to explore. Joutsenvirta and Myyry (2010) described an online biodiversity database produced to assist undergraduate biology students. Students had the opportunity to produce their own digital herbaria and identification resources from fieldwork which, if high quality, were incorporated into the database for the benefit of future students. One of the foci of the European project *KeytoNature* (2007 to 2010) was the provision of software that allowed teachers to produce keys tailored to specific user audiences, groups of organisms or localities (Martellos 2010a).

Educational Implications of Study

The printed key used in this study was more effective than the electronic key, demonstrating that such keys are not obsolete as suggested in the literature. A precautionary note to add is that the study only tests one type of paper-based key and one electronic key, rather than general principles of key types, and the paper-based key in this study was more efficient in its design than the electronic key. A flowchart format is easy to follow and allows for immediate comparisons of similar species, whereas electronic keys rely on user selection for information displayed. Well-designed printed keys are currently easier for non IT specialists to produce than multi-access electronic keys of similar quality. Teacher-led keys allowed content to be tailored to curriculum or locality, which, as explored in the previous section, have much potential for inquiry-based learning and nature connections.

The design of a key is therefore more important than its presentation medium and careful selection and testing of differentiation cues, terminology, artwork, and key navigability are required for any key type to be effective. Professionally produced digital keys and other digital resources have much to offer biological education, particularly the most recent iPod identification apps. Their potential value in field biology is determined by the educational institution's access to suitable mobile devices and the capacity to update these as newer models supersede existing ones. Finally, the use of multiple media in taxonomic education is, as ever, important for meeting the needs of a range of students and learning environments.

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Mnemonics are an Effective Tool for Adult Beginners Learning Plant Identification

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Most beginners are introduced to plant diversity through identification keys, which develop differentiation skills but not species memorisation. We propose that mnemonics, memorable 'name clues' linking a species name with morphological characters, are a complementary learning tool for promoting species memorisation. In the first of two experiments, 64 adults in a group-learning environment were taught species identification using mnemonics, an educational card game and a text-based dichotomous key. In the second experiment, 43 adults in a self-directed learning environment were taught species identification using mnemonics and a pictorial dichotomous key. In both experiments, mnemonics produced the highest retention rates of species identification based on vegetative characters. The educational value of these findings is discussed for vegetative plant identification and broader applications.

Keywords: *Plant identification; botany; taxonomy; mnemonics; identification key*

Introduction

The decline in interest in plants in biological education is an established phenomenon (e.g. Stagg et al. 2009; Levesley, Jopson, and Knight 2012; Nyberg and Sanders 2013). Compared to animals, plants are under-represented in biology textbooks and other media (Uno 2009; Perez et al. 2010). Biology teachers often avoid using plant examples in class due to their own lack of knowledge or interest, perpetuating the cycle (Bebbington 2005; Uno 2009). With botanical topics often relegated to single modules or lecture sets and limited opportunities for fieldwork, learning of species identification has inevitably suffered (Goulder and Scott 2006). Bebbington (2005) found that 29% of A-level biology teachers and 86% of their students were only able to recognise three or fewer out of 10 common wild flower species. Species identification is a fundamental requirement for learning and understanding biodiversity, but it also plays a role in fostering concern for its preservation (Randler 2008). Plant identification draws people's attention to the wide

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variation in plant form, texture, colour, etc., increasing their interest in plants and their appreciation of biodiversity (Lindemann-Matthies 2006; Strgar 2010). Given the rapid rate of decline of plant species and consequences for wider ecosystems, there may be a greater need than ever to find ways to promote identification skills not only in the classroom but among the general public.

Providing botanical instruction in a lifelong learning context may be one way to address its neglect in formal education (Stagg and Donkin 2013). In fact, fostering personal interest in natural history is more likely to lead to in-depth and lifelong learning than formal education alone (Goulder and Scott 2009). Learning how to identify plants by attending public courses builds necessary confidence for pursuing plant ecology as a hobby or a career. This learning has the added benefit of enabling citizens to directly contribute to botanical monitoring and conservation through participating in recording schemes like those organised by Plantlife and Botanical Society of Britain and Ireland. Since 2008, we have organised a programme of botanical events as part of the national project OPAL and plant identification events have been well attended by students and citizens alike.

Keys have long been considered the most important way of learning to identify new species (e.g., Pankhurst 1978; Lawrence and Hawthorne 2006; Stagg, Donkin, and Smith 2014). Keys may be dichotomous or multi-access, printed or electronic, and are often incorporated into an identification guide about the species' ecology. A well-designed key is meant to develop in the learner the ability to locate and distinguish between the most relevant diagnostic characters for identification. Keys are an inquiry-based learning method of learning about biodiversity, proven to produce greater retention of new knowledge and higher intrinsic motivation than teacher-led methods (Randler 2008; Pfeiffer, Scheiter, and Gemballa 2012; Schaal, Grübmeyer, and Matt 2012). But are keys the most efficient way to promote the sort of memorisation that leads to direct recognition? Worthen and Hunt (2011) warn of the common but incorrect assumption that memorisation 'comes for free' in the learning process. Burrows (2012) bemoans the fact that in Australia, whilst an abundance of materials are available for identifying native plant species, resources to develop species memorisation skills are scarce (in our experience this is also true in the UK). In this study, we compare species-recognition skills developed through the use of keys with that of two other popular methods: mnemonic devices and game-playing.

Keys may have several shortcomings with respect to promoting efficient species memorisation. According to cognitive load theory (Randler and Birtel 2008), constraints on working memory limit the amount of information that the mind can process and translate into learning (Sweller 1994). A 'keying-out' activity is a complex task with a high cognitive load that is likely to reduce the working memory available for species memorisation (Randler and Birtel 2008). A key that relies on botanical terminology will add to cognitive load, since the beginner is required to master a new set of vocabulary at the same time. The keying-out process also divides attention among a variety of things, only one of which is the view of the species as a single entity. This has two implications for learning. First, feature unitisation, an aspect of perceptual learning that facilitates recognition (Goldstone 1998), is enhanced by focusing on the species in isolation rather than in relation to other species and focusing on its characteristics in unity rather than in sequence.

Second, according to the principle of transfer-appropriate processing, ease of recall depends on the similarity of processing at encoding and retrieval (Morris, Bransford, and Franks 1977). Processing that occurs with use of a key differs considerably from the process of simple, direct recognition.

A mnemonic is a memorisation technique that converts information into a form more easily remembered than its original form (Worthen and Hunt 2011). The emphasis that mnemonics place on visual information, associations and hierarchical concepts make them a natural fit to biology, a discipline in which all of these are integral. Rosenheck, J. Levin, and M. Levin (1989) found mnemonic approaches to be more effective than 'own best method' and taxonomic approaches for learning plant classification. Carney and Levin (2003) found mnemonics to be more effective than 'own best method' for undergraduates identifying fish species. They used keyword mnemonics in which the species name is associated with a familiar, acoustically or orthographically similar word or phrase. The word or phrase, together with the characteristics of the species, is used to generate a memorable image; these provide accessible retrieval links back to the species name. Killingbeck (2006) also found the keyword method to be an effective memorisation strategy in a qualitative study of undergraduate students studying plant taxonomy.

Educational card games have been used to promote recognition and memorisation. This engaging format has shown to be effective for learning to identify plant species, groups of satellites, chemical elements and formulae (Sevcik et al. 2008; Smith and Munro 2009; Morris 2011; Stagg and Donkin 2013). The efficacy of educational card games as learning tools may be dependent on the degree of repetition (since repetition promotes object memorisation), the cognitive load associated with strategic aspects of the game and the extent to which gameplay emphasises recognition of species characteristics.

In Experiment 1, we compared species retention produced by three teaching methods used in a group-learning environment: a text-based dichotomous key; learner-generated mnemonic aids; and a pictorial card game. Text-based keys have the advantage of encouraging close attention to the characters in the key rather than reliance on matching specimens to photographs or illustrations (Randler and Birtel 2008; Randler 2008). The keys used here were tailored to plant groups and minimised the use of botanical terminology to make them accessible for complete beginners with varying levels of literacy (Ohkawa 2000). In Experiment 2, we compared species retention gained through full-colour pictorial dichotomous keys and author-generated mnemonic aids in a self-directed learning environment. Like Experiment 1, keys were tailored to plant groups but did use botanical terms where this assisted differentiation, accompanied by definitions, annotated diagrams or both. Study participants were student and conservation volunteers attending to learn new identification skills.

Methods

Aspects of experimental design, including the number of focal species and the length and format of research trials, were informed by previous studies conducted by the authors (e.g., Stagg and Donkin 2013; Stagg, Donkin, and Smith 2014). The research trials were the primary component of a public event which culminated with discussion and further learning about the focal species (species ecology and ethnobotanical uses, observing field specimens, etc.). Randomising operations used number sets obtained from a random number-generating website.

Method: Experiment 1

Seven half-day events were held during January and February 2012, in Plymouth and South Devon, as part of the national initiative OPAL (Open Air Laboratories). Events were organised for specific interest groups as shown in Table 1. A total of 64 people (27 female; 37 male) participated in the trials. The mean age was 25.6 years. The OPAL Community Scientist and a postgraduate volunteer facilitated the events.

Each research trial consisted of an introduction followed by three 30-min teaching sessions, with a different group of 10 plants and activity (keying out exercise, mnemonics, pictorial card game) used in each session. Each 30 min session commenced with a written identification test to measure existing knowledge of the 10 plants. The test was repeated, with the plants in a different order, at the end of the session to assess species retention. Combinations of plant groups and teaching activities were randomly selected for each event, meaning there was a total number of 36 possible combinations. The 30 plants were native winter hardy perennial herbs selected from the college campus grounds and randomly divided into three groups of 10 plants. A few species were naturalised rather than strictly native, e.g. *Cymbalaria muralis.* Plant specimens were dug up in October 2011 and potted into 0.3 or 0.5-litre pots depending on plant size. Potted plants used for instruction were labelled by name, whereas plants used for tests were labelled by number.

In key sessions, participants working in pairs identified the 10 plants using the dichotomous key for that plant group. The session tutor corrected any mistakes and participants had time to study the specimens and species names at the end of the session. In mnemonic sessions, participants worked as a group to develop text-based mnemonics linking the species name with an identification character. Participants were told the species' common name and spent time reflecting on and discussing potential mnemonics, with the tutor contributing from a list developed by the authors prior to the events. Table 2 gives examples of popular mnemonics. The participants spent time at the end of the session studying the specimens, using the mnemonics that were most effective for them. In card game sessions, participants played a game in small groups, using laminated cards of the species in that plant group (Figure 1). This was the classic game of 'Memory': 20 cards

Table 1. Breakdown of event participants in experiment 1

Participant background	**Number of participants**
Undergraduates at Plymouth University (mainly first-year life science students)	36
Recently enrolled horticulture students at Duchy College	9
Trainees enrolled on an employment scheme with conservation charity TCV, Plymouth	13
Volunteers from TCV's youth volunteering branch, Plymouth Environmental Action	6

Table 2. Examples of mnemonics popular in Experiment 1

Species common name	Species botanical name	Mnemonic
Red campion	*Silene dioica*	The **champion** leaf with the **furry chest**!
Field speedwell	*Veronica persica*	Leaves are few on the stem but become clustered towards the tip – they **speed-well** up!
Herb Robert	*Geranium robertianum*	Stems of Herb Robert are red, Robert is red like **Robert Redford**!
Lungwort	*Pulmonaria officinalis*	Leaf like a **pair of lungs** upside down, with **white blotches like 'warts'**
Ivy-leaved toadflax	*Cymbalaria muralis*	**Ivy-shaped leaves** which are **fleshy like a toad**
Cleavers	*Galium aparine*	**Sticks and pulls** at your fingers, feels like it is **cleaving** through your skin!
Red dead-nettle	*Lamium purpureum*	Leaves look like stinging nettle leaves but they **don't sting** as they're **'dead nettles'**

(two for each species) were shuffled and placed face down. Each participant could turn over two cards of their choice in their turn, with the aim of locating a matching pair. Participants were required to call out the species names on the card as these were turned over, to promote learning.

Method: Experiment 2

A comprehensive species survey of native and naturalised winter hardy perennial herbs was conducted in the four-acre college campus grounds in March 2013, using Rose et al. (2006). Of the 47 species identified, 12 were excluded because they were considered to

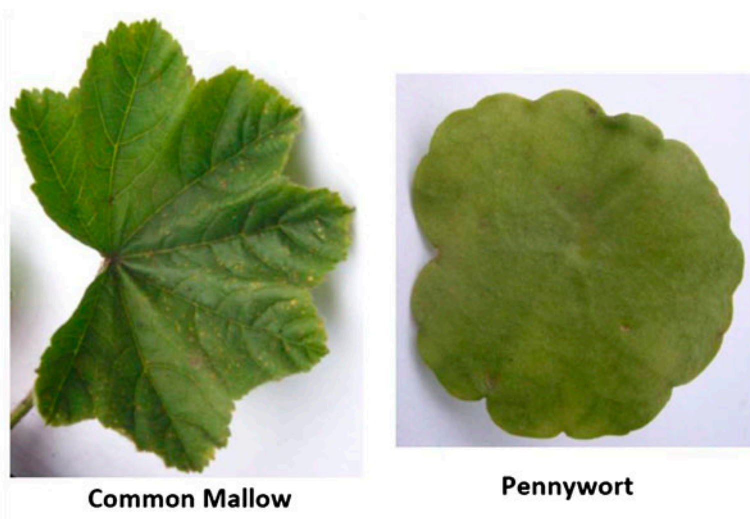


Figure 1. Examples of laminated cards used in card game

be common knowledge (based on the pre-test results of Experiment 1 and Stagg and Donkin 2013). A further six were excluded because populations were too sparse to yield sufficient specimens for the experiment. Of the remaining species, 24 were selected for the experiment. Mnemonics for each species were generated building on the those developed in Experiment 1.

Five two-hour events were held in March and December 2013, in Plymouth and South Devon. The lead author and a contracted ecology tutor were responsible for event delivery. Events were open to the general public and a total of 43 participants attended, including approximately eight 'Friends Group' volunteers, 10 university staff and students (24 female, 19 male). The event consisted of an identification pre-test on the 24 plant species, instruction, two self-directed activities (dichotomous key, mnemonics), a five-minute distraction activity (unrelated word puzzles), identification post-test and completion of a summative questionaire and discussion. The 10-min instruction covered use of a dichotomous key, hand lens and mnemonics, followed by a demonstration of basic morphological characters in a vegetative specimen. The summative questionnaire served to assess participants' experiences and preferences using Likert-scale ratings and open-ended questions (Taraban et al. 2004).

A different group of 12 plants was used for each activity. The order of the activities and plant group assigned to each was randomised for each individual. For each activity, participants were provided with a box file containing either the dichotomous key or the guide to mnemonics and 12 live plant specimens numbered using sticky labels. Specimens were harvested prior to the event, with whole plant specimens selected wherever possible. The dichotomous keys and guides to mnemonics were produced using colour photos of species and black and white illustrations for botanical terms (Figures 2 and 3).

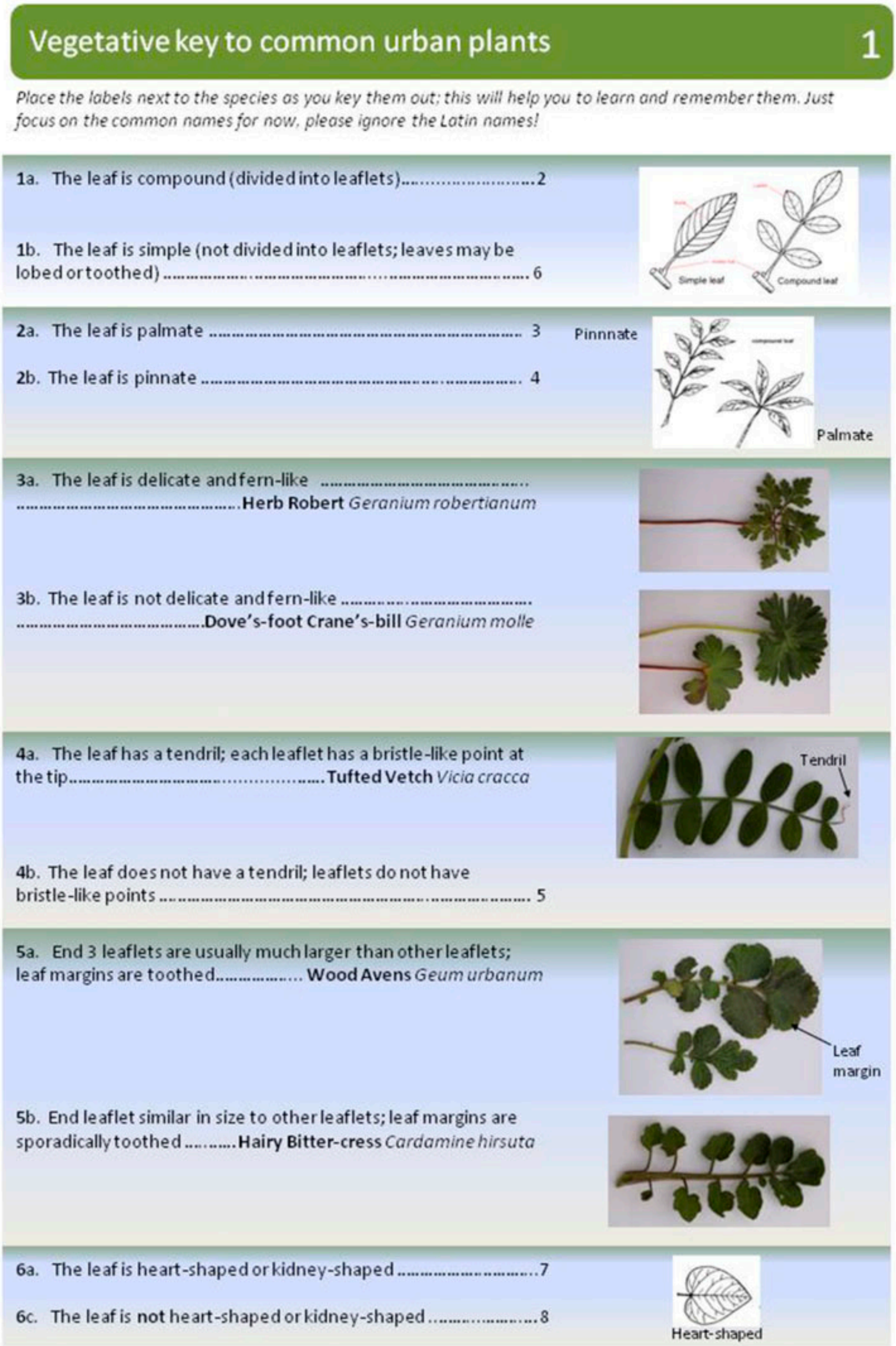
Participants were given 12 min to complete the mnemonic activity and 24 min to complete the key activity. During the activities, the instructor provided help and encouragement to participants, assisting them in interpreting instructions and plant characters when required and monitoring participants' progress. Plant specimens and activity sheets were returned to the box files after each activity and were not visible during the distraction exercise or post-test. A different set of plant specimens were used for the pre-test and post-test identifications, and the ordering of species differed within each test.

Data analysis

The retention rate was defined as the difference between pre-test and post-test identification scores. Pre-test scores indicated that a small number of individuals attending events were not beginners. Data for these individuals would be misleading, since potential learning is restricted by high existing knowledge. To remove these outliers, datapoints with a pre-test score greater than two standard deviations from the mean were excluded from the data-set.

Results: Experiment 1

Eight non-beginners were excluded from the data-set prior to analysis. An additional five individuals were excluded due to illegible or incomplete data. A significance level of



Vegetative key to common urban plants 1

Place the labels next to the species as you key them out; this will help you to learn and remember them. Just focus on the common names for now, please ignore the Latin names!

1a. The leaf is compound (divided into leaflets)........................2

1b. The leaf is simple (not divided into leaflets; leaves may be lobed or toothed)..6

2a. The leaf is palmate 3

2b. The leaf is pinnate 4

3a. The leaf is delicate and fern-like .... **Herb Robert** *Geranium robertianum*

3b. The leaf is not delicate and fern-like .... **Dove's-foot Crane's-bill** *Geranium molle*

4a. The leaf has a tendril; each leaflet has a bristle-like point at the tip..**Tufted Vetch** *Vicia cracca*

4b. The leaf does not have a tendril; leaflets do not have bristle-like points 5

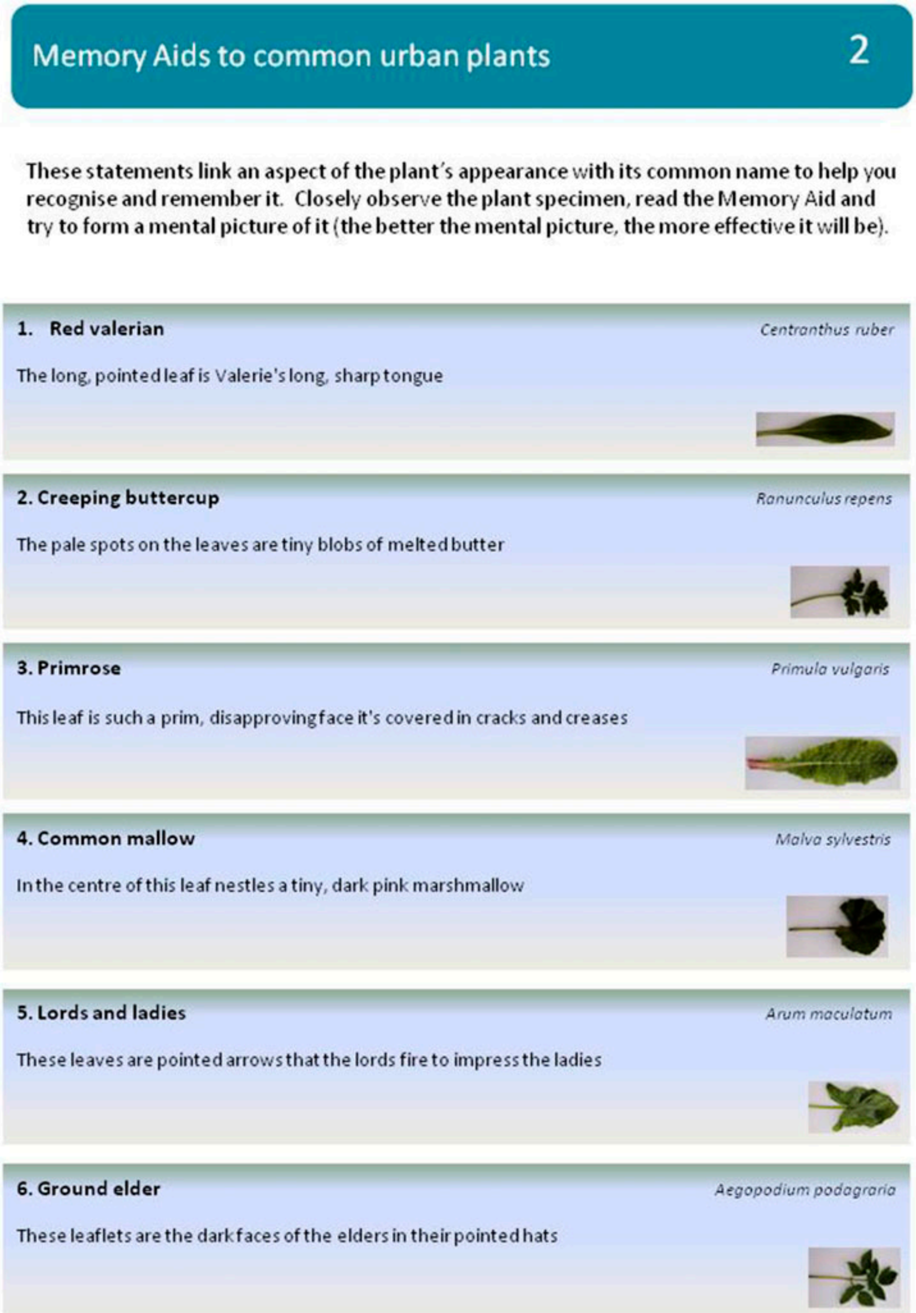
5a. End 3 leaflets are usually much larger than other leaflets; leaf margins are toothed.................. **Wood Avens** *Geum urbanum*

5b. End leaflet similar in size to other leaflets; leaf margins are sporadically toothed ....**Hairy Bitter-cress** *Cardamine hirsuta*

6a. The leaf is heart-shaped or kidney-shaped 7

6c. The leaf is **not** heart-shaped or kidney-shaped 8

Figure 2. Excerpt from identification key used in Experiment 2


Memory Aids to common urban plants 2

These statements link an aspect of the plant's appearance with its common name to help you recognise and remember it. Closely observe the plant specimen, read the Memory Aid and try to form a mental picture of it (the better the mental picture, the more effective it will be).

1. Red valerian *Centranthus ruber*
The long, pointed leaf is Valerie's long, sharp tongue

2. Creeping buttercup *Ranunculus repens*
The pale spots on the leaves are tiny blobs of melted butter

3. Primrose *Primula vulgaris*
This leaf is such a prim, disapproving face it's covered in cracks and creases

4. Common mallow *Malva sylvestris*
In the centre of this leaf nestles a tiny, dark pink marshmallow

5. Lords and ladies *Arum maculatum*
These leaves are pointed arrows that the lords fire to impress the ladies

6. Ground elder *Aegopodium podagraria*
These leaflets are the dark faces of the elders in their pointed hats

Figure 3. Excerpt from mnemonic guide used in Experiment 2

$\alpha = .05$ was adopted for all tests. Paired-samples *t*-tests identified significant differences in retention rates for the three activities. As Figure 4 shows, the mnemonic activity produced a higher retention rate than either the card game, $t(50) = 3.63$, $p = 0.001$, or the key, $t(50) = 5.69$, $p < 0.001$. The card game produced a higher retention rate than the key, $t(50) = 2.60$, $p = 0.012$.

Results: Experiment 2

Two non-beginners were excluded from the data-set. Prior to analysis, scores were subjected to square root transformations to satisfy normality assumptions. A paired-samples *t*-test identified a significant difference in retention rate between the two activities, $t(40) = 4.003$, $p < 0.001$. As Figure 5 shows, the mnemonic activity produced a higher retention rate than the keying out activity. The species that produced the highest retention rates in post-test following the mnenonic treatment are shown in Figure 6.

Participants completed a written questionnaire with an open question asking for their opinions on the two learning methods. The most common responses are shown in Table 3.

A subset of 22 participants scored the two activities using three criteria (Table 4). 74% of this subset named the mnemonic activity as the 'preferred activity overall' and 74% had used a species identification key before, whereas only 32% had used mnemonics for

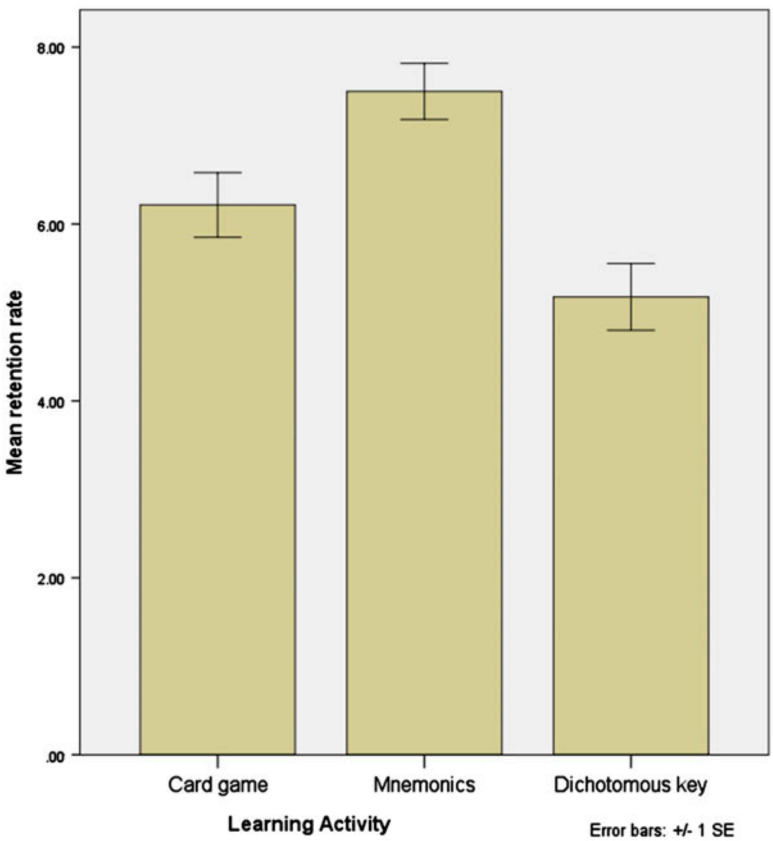


Figure 4. Retention rates of species identification following learning in Experiment 1

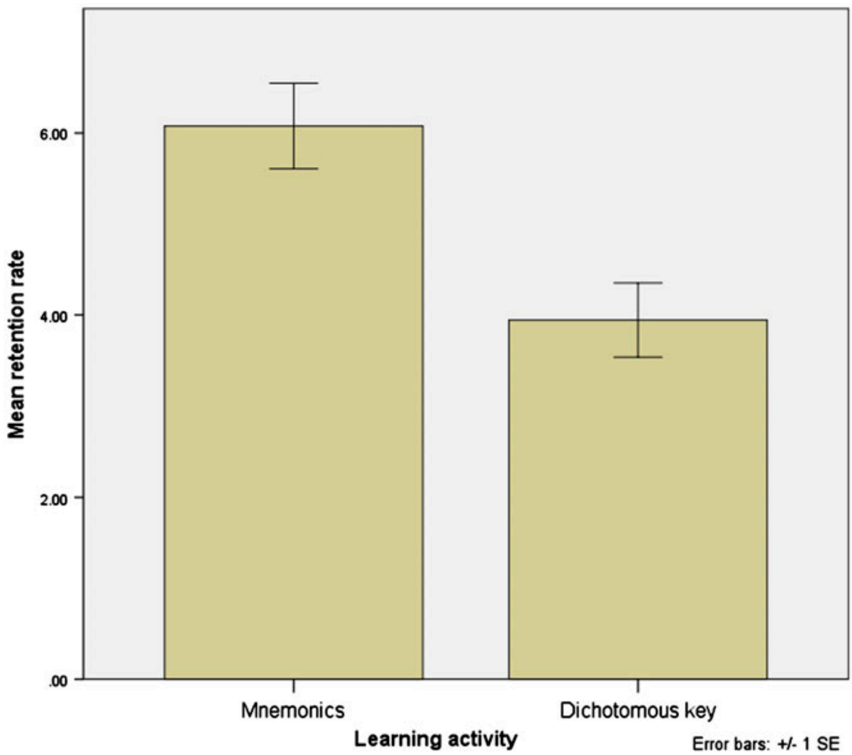


Figure 5. Retention rates of species identification following learning in Experiment 1

memorising species (e.g., for plants, fish, or coral species). In addition, 14% had used mnemonics for language learning or remembering names of new acquaintances.

Discussion

Effect of teaching methods on species recognition

In both experiments, mnemonics proved superior to other methods for improving species recognition. In Experiment 2, the advantage was achieved in half the time of the keying-out activity. In some respects, these findings may not be surprising. Mnemonic methods are designed specifically to facilitate direct recognition; their efficacy is well understood in memory research (Worthen and Hunt 2011) and a number of studies have described their successful application to biological topics (e.g. Rosenheck, J. Levin, and M. Levin 1989; Atkinson et al. 1999; Carney and J. Levin 2003). As noted earlier, keys may be less efficient at promoting feature unitisation, an aspect of perceptual learning important for fast recognition, and the keying-out procedure diverts attention to processes other than memorisation. The advantage of the 'Memory' card game over the key in Experiment 1 likely arises for similar reasons. With the game, however, memorisation is based on the participant's own strategies, which will tend to be less effective than formal mnemonics.

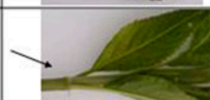
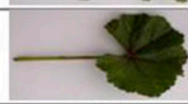
Plant Species	Mnemonic	Image
Lords and ladies	These leaves are pointed arrows that the lords fire to impress the ladies	
Cow parsley	This giant sprig of parsley would make a good garnish for a cow's dinner plate	
Red valerian	The long, pointed leaf is Valerie's long, sharp tongue	
Primrose	This leaf is such a prim, disapproving face it's covered in cracks and creases	
Ground ivy	The goblin put ground-up ivy in the King's drink to make his kidneys go green	
Dog's mercury	At the point where the leaves join the stem are tiny pointed dogs' teeth	
Teasel	The sharp points on the surface of the leaves are the claws of a weasel	
Hogweed	Look at the stems; they are the red, rough, hairy skin of a hog	
Common mallow	In the centre of this leaf nestles a tiny, dark pink marshmallow	

Figure 6. Species with highest retention rates in the mnemonic activity

Table 3. Responses to an open question inviting feedback on the two activities

Feedback comment	Frequency
Linking characters to names is a valuable/fun/enjoyable way of learning plant species	10
The memory aids worked well for some species but were less useful for others	9
The key was a useful exercise but does not help with remembering species	8
The memory aids taught me new ways to differentiate between species	6
The key activity made me anxious/was stressful	5
Combining the two methods would be an effective approach to plant identification	4
The memory aids would be less useful if you were trying to learn a large number of species/field identification	4
The key taught me new ways to differentiate between species/new identification skills	4

Table 4. Mean score in response to the feedback question: 'Please rate each activity from 1 to 5, for the following (1 = "low" and 5 = "high")'

	Mnemonics	Identification key
How effective the activity was in helping you to learn the set of plant species	3.48	2.10
How enjoyable you found the activity	4.05	3.25
How valuable the activity was in teaching you about plants and their identification	3.05	4.05

Comments from the questionnaire highlight the importance of keys for developing broader taxonomic skills, however. In Experiment 2, key use promoted diagnostic skills more than mnemonics did, with 36% of participants describing learning specific to morphological characters for the key compared to 5% for the mnemonics. Participants scored the key at 4.05 out of 5 in response to 'how valuable the activity was for teaching you about plants and their identification,' compared to 3.05 for the mnemonics. A key draws attention to reliable diagnostics rather than superficial characteristics and develops an understanding of what constitutes a species (Kirchhoff et al. 2011). Developing proficiency in key use and recognition of reliable diagnostic characters are the kind of skills that lead to higher order understanding, whereby learning can be generalised to newly encountered plant species (Krathwohl 2002; Carney and Levin 2003).

We do not propose that mnemonic devices should ever supersede the learning and practice of identification keys. Experience with keys promotes skills, such as knowledge of morphology across families, which are important in their own right and essential for the pursuit of field botany. However, it is easy to underestimate the importance of direct recognition for which memorisation strategies like mnemonic devices appear particularly effective. For students, direct recognition of species complements the use of keys in identification, which together could promote the cumulative learning that is such an important component of species identification. Comparing a newly encountered species to stored images allows for rapid elimination and focus on a shortlist of taxonomic ranks that the new species may belong to (Lawrence and Hawthorne 2006). Fast and efficient access to information promotes flexible and creative use of that information, which may contribute to higher order understanding (e.g. Carney and Levin 2003). Finally, the use of mnemonics has additional benefits for public engagement. They are an easily implemented and enjoyable way to develop basic identification skills in a short amount of time, which could lead to a more serious interest in field botany.

A limitation of the study is that long-term retention of species identification was not measured. We do not know, therefore, if the species-memorisation advantage of the mnemonics in this study is durable over time. We also do not know how the mnemonics used in this study assist in learning new species identifications, compared to the diagnostic skills acquired through key practice. Rosenheck, J. Levin, and M. Levin (1989) found that the recall advantage of mnemonics for memorising a plant classification system (compared to 'own best method' and traditional taxonomic method) still applied two days and one month following learning treatments. Carney and Levin (2003) proved that the recall advantage of mnemonics for identifying fish species (compared to 'own best method') still applied two days following learning. Mnemonic students also outperformed control students on a task requiring them to apply the learnt information to new information.

Designing effective mnemonic devices

In Experiment 2 we investigated which species produced the highest retention rates following the mnemonic method (Figure 5). We might assume this to be a shortlist of our most effective mnemonic devices and, indeed, it includes some of the mnemonics that were most popular with the participants. Retention rates may also be affected by differences in species distinctiveness, e.g. leaf shape. Randler (2008) found that species with a clue to their appearance or other association in the name produced retention rates of 60–70%, compared to 40% for species with no name clues. This might account for the high retention rate for cow parsley and possibly ground ivy.

One participant noted that the mnemonic devices would be more effective if they included pictures; for example, 'lords shooting arrows to impress the ladies' for lords and ladies (*Arum maculatum*). The efficacy of illustrated mnemonic devices has been shown by Rosenheck, J. Levin, and M. Levin (1989) for learning plant classification, and by Carney and Levin (2003) for identifying fish species. One approach to designing effective mnemonics is to break the species name up and generate name cues for each fragment. This approach would be particularly effective for the longer, more complex botanical names, as demonstrated by Killingbeck (2006). Self-generated mnemonics like the ones used in Experiment 1 can be more effective than those provided by others, but creating them can be daunting and time-consuming for learners new to mnemonics (Slamecka and Graf 1978).

Worthen and Hunt (2011) noted that the use of mnemonics should always involve a cost–benefit consideration. Several people commented in the questionnaire that devices were more useful for some species than others. Their usefulness is more limited with larger suites of species when differentiation is low and there is a heavy reliance on common characters, e.g. leaf shapes, in the mnemonic devices. Mnemonics may therefore be best applied to a limited suite of species, such as those found in a particular locality, as a way for learners to develop identification confidence before progressing onto a novel set of species. Mnemonics are best with distinctive species—for example, lords and ladies, with its unusual leaf shape, or dog's mercury (*Mercurialis perennis*), with its distinctive leaf stipules. Another potential problem is a reliance on characters such as leaf or stem coloration, which exhibit high intra-species plasticity and are often absent from juvenile leaves (Rose et al. 2006). This issue might be dealt with by using devices that incorporate multiple characters, e.g. 'red and hairy like a hog' for hogweed (*Heracleum spondylium*).

Mnemonics are therefore best applied judiciously in species identification, preferably after the learner has identified the species by a diagnostic method. Over-reliance on mnemonics would not also reduce their efficacy but risks creating a parallel taxonomic structure, which would be both confusing to learners and detrimental to the pursuit of field botany.

Participant enjoyment of teaching methods

As well as producing a higher retention rate than the dichotomous key, the mnemonics were more popular with participants in Experiment 2. Seventy four percent of participants preferred the mnemonic activity and it received a score of 4.05 out of a possible 5 for enjoyment, compared to 3.25 for the key. One reason may be because the keying-out activity was time-consuming, taking 20 min to key out the 12 species, in spite of the simple, plain English format of the tailored key and the fact that most participants (74%) had used a dichotomous key before. Five participants described the keying out activity as 'stressful' in the summative questionnaire. Enjoyment is, of course, an important element of effective learning by promoting intrinsic motivation, as well as helping to dispel the image of botany as 'dull and dusty' (Uno 2009). Only 32% of participants in the study had encountered mnemonic devices, affirming that this is a novel memorisation strategy for novices learning species identification.

Angiosperm identification using vegetative specimens

In this study, we chose to focus on angiosperm species identification based on vegetative characters, for a number of reasons. Many beginners' botanical identification guides are based on plants in flower, which are easier to identify than vegetative specimens, as they differ more dramatically in morphological characters (Bloniarz and Ryan 1996). But most native species only flower for two or three months of the year, whereas they occur in the asexual phase for several months of the year (Rose et al. 2006). Keys to vegetative characters are only accessible to botanists with some experience, as they rely on a good knowledge of botanical terminology and character recognition (e.g. Poland and Clement 2009). The number of species a beginner encounters in their immediate environment, for example garden, campus or neighbourhood, is sufficiently limited that species differentiation can be learnt without mastering a published vegetative key, for this preliminary suite of species. Focusing on species identification skills that learners can apply in their local environments over an extended period is proven to promote botanical literacy (Lindemann-Matthies 2006; Sanders 2007; Nyberg and Sanders 2013; Stagg, Donkin, and Smith 2014). The majority of the species used in this study were ephemeral or winter-hardy species, common in urban environments and with a short or entirely absent winter dormancy phase in the UK. These provide a valuable study group for biology educators and technicians, who are frequently faced with designing laboratory or field practicals in the autumn and spring terms. Since botanical identification is most effective when live specimens are used, the value of a specimen group that is available and easily accessible is self-evident (Taraban et al. 2004; Teolis, Peffley, and Wester 2007).

Learning plant species identification

Biology and horticulture students typically encounter plant species through fieldwork involving teacher-led instruction, practice in identification keys, practice in habitat survey techniques, or a combination of all three. The field trips organised by amateur botany societies can offer similar experiences, albeit with a greater emphasis on peer-to-peer learning. Specimens may be collected for drawing and labelling following the field trip, or pressed as part of a herbarium project. If fieldwork occurs in the college grounds, specimens may be labelled or flagged *in situ* to allow students to return and scrutinise these as part of the learning. These teaching approaches are discussed in depth by Lindquist, Fay, and Nelson (1989); Goulder and Scott (2006; 2009); and Teolis, Peffley, and Wester (2007).

A variety of resources are now available for self-directed botanical learning. In 2009, The Open University launched an online nature community called iSpot as part of OPAL. Users upload images of species and online experts and amateurs assist with identification (www.ispotnature.org). Tablets and other mobile devices allow for uploading of images in the field and there are now nearly 20 iPod and Android identification apps for trees or wildflowers in the UK. Isoperla's wildflower app features a botany quiz, allowing for self-testing on the species learnt (http://isoperla.co.uk/WildFlowerIdiPhone.html).

Educational implications of study

Mnemonics are a useful teaching method in taxonomic education, alongside identification keys and other aspects of experiential fieldwork. Identification keys develop diagnostic skills whilst mnemonics assist the memorisation processes that produce direct recognition of species. As well as offering students an alternative to laborious rote learning, this allows novices to develop their field identification skills without frequent referral to an identification guide. Mnemonics are most effective for highly distinctive species and limited suites of species, suggesting that they may be most valuable for building confidence in identification before introducing learners to the full extent of species in the field environment. Participants in this study also enjoyed mnemonics more than a keying-out activity, suggesting that they could help to stimulate interest in botany.

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Apps for angiosperms: the usability of mobile computers and printed field guides for UK wild flower and winter tree identification

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ABSTRACT
We investigated usability of mobile computers and field guide books with adult botanical novices, for the identification of wildflowers and deciduous trees in winter. Identification accuracy was significantly higher for wildflowers using a mobile computer app than field guide books but significantly lower for deciduous trees. User preference followed a similar pattern. These results suggest that the identification method and its design are more important for a field guide than its presentation medium (electronic or printed). We discuss the relative advantages of the presentation media used and their value as engagement tools for botany.

KEYWORDS
Mobile computers; plant identification; keys; apps; handheld computers

Introduction

Biological identification, the process of determining which taxon a specimen belongs to, is a fundamental skill for understanding the natural world (Dallwitz, Paine, and Zurcher 2002). The 'taxonomic impediment' to biodiversity conservation has been recognised in international policy, and public awareness and education is highlighted as one of the key actions (Convention on Biological Diversity 2014). University and school students have particularly poor botanical identification skills, which is not surprising as some biology teachers are weak in this area (e.g. Bebbington 2005; Stagg and Donkin 2013). The school biology curriculum may also be responsible, by using plants merely to illustrate biological processes, rather than drawing attention to botanical diversity and its relevance to topical environmental issues (Stagg et al. 2009). Novel and effective learning media for botanical identification may help to address these problems.

Field guides, portable reference tools for identifying taxa, are commonly used by amateurs, students and scientists alike (Lawrence and Hawthorne 2006). Botanical identification guides have been in existence since Lamarck's 'Flore Francoise' in 1779, whose dichotomous key, user-friendly layout and use of French instead of Latin were accessible to a lay audience (Scharf 2009). In 1803, Dubois produced the first tripartite field guide, called 'La Methode Eprouvee', which was refined over several years through testing with students (Scharf 2009). The tripartite design accommodated different skill levels. Users that already knew the species could locate it using the index; familiar species could be determined by looking up similar species and browsing the species descriptions in the adjoining pages;

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if the species was unknown, the user worked through the key. Most field guides since have followed a similar format, albeit with the proliferation of colour illustrations in the last 100 years and cumulative improvements in presentation and layout (Scharf 2009; Leggett and Kirchoff 2011).

The advent of handheld computers could be the next significant development in field guides. Computer-based identification keys are not a recent development; indeed, the first such keys were produced in the late 1960s (Dallwitz, Paine, and Zurcher 2002). But it was another 30 years before computer hardware became sufficiently durable and portable to allow for electronic identification in a field environment (De Vaugelas et al. 2011). Handheld computers include tablets (e.g. iPad and Tab) and smartphones (e.g. iPhone and Android) and there are more than 1.75 billion global users (Emarketer 2014). Custom-designed software applications, called apps, could be particularly valuable for field use since, once downloaded, they do not require mobile reception (Araya 2013). Mobile apps are downloaded from the brand's distribution platform to the device e.g. the App Store for Apple's iOS, (iOS is the interface for iPad, iPod and iPhone) and Google Play for Android.

The choice of field guide apps is limited at the moment, with around 20 botanical apps for Android and 30 for iPhone devices, compared to more than 2000 botanical field guide books in circulation worldwide (International Field Guides 2014; Google Play 2015; iTunes 2015). Like printed guides, many apps featured species descriptions and an index or gallery, as well as a key. Other features include identification quizzes and the option to upload images or locations of sighting to share with other users. The latter has led to 'a new dawn for citizen science' (Silvertown 2009), with mobile computing enabling 'mass participation' biodiversity surveys.

Identification keys are based on characters (observable features e.g. colour), defined by character states (categories e.g. blue or yellow) (Lawrence and Hawthorne 2006). Most computer-based keys are multi-access, meaning that the sequence of steps is not fixed in a particular order and multiple character states are available at each step (Farr 2006). The user may choose their route through the key and identification is still possible if certain steps are omitted. Printed keys are usually dichotomous, requiring the user to follow a sequence of steps, with a choice between two character states at each step (Drinkwater 2009). Increasingly, field guide books aimed at beginners use a 'polychotomous' key or 'structured browsing' (Stevenson, Haber, and Morris 2003; Lawrence and Hawthorne 2006). In a 'polychotomous' key, users choose from multiple character states in a single step or short sequence of steps. In 'structured browsing', similar species or families are grouped according to simple characters (e.g. flower shape), which direct the user to the relevant section of the book.

There are many proponents of computer-based keys (e.g. Dallwitz, Paine, and Zurcher 2002; Farr 2006; Drinkwater 2009), but few have been tested empirically alongside printed keys. Research is needed about the processes by which digital tools may contribute to successful learning (Donoso and Calvi 2008). Morse, Tardivel, and Spicer (1996) compared a multi-access key with printed dichotomous key for woodlice identification and found no difference in student accuracy. Stagg, Donkin, and Smith (2014) proved that a dichotomous printed key with a flow chart design was more efficient and accurate than a comparative multi-access electronic key for bryophyte identification. There are few scientific studies on the usability of field guides, particularly the structured browsing or simple keys employed by many beginners' printed guides (Stevenson, Haber, and Morris 2003). Electronic field guide apps clearly have the potential to be important educational tools, but there has as yet been little assessment of their scientific accuracy or ease of use and how they compare to printed counterparts.

This study explores the usability of an iOS app on iPod devices alongside two printed guides, for the identification of common wildflower and tree species, respectively. Hawthorne and Lawrence (2013) define usability of an identification guide as a measure of its effectiveness (enables user to make a positive identification), efficiency (minimises time and effort required from user) and satisfaction (enjoyment from using the guide). Key effectiveness was assessed by measuring the number of species correctly identified by participants using a particular guide. Key efficiency and key satisfaction were assessed from time taken to complete identification and a 'post activity' self-reported evaluation. iOS apps and printed guides were selected by the authors, according to quality and suitability for novices. Wildflowers and trees were selected because they are popular taxa with beginners, as demonstrated by the variety of guides available compared to other taxa. The species used were predominantly native but included a few naturalised species. Trees were all broad-leaved deciduous species identified in winter and included a few large shrubs, e.g. *Prunus spinosa, Crateagus monogyna.*

Methods

Experimental designs were informed by the authors' previous studies (e.g. Stagg, Donkin, and Smith 2014; Stagg and Donkin 2015), including the number of focal species, length and format of research trials.

Identification media

Twenty-eight popular identification guides for British trees and wild flowers were assessed by the authors and three guides selected for each taxon (Tables 1 and 2; Figure 1). Guides were chosen that demonstrated different approaches to plant identification, innovation and suitability for novices, as discussed by Leggett and Kirchoff (2011), Lawrence and Hawthorne (2006) and Farr (2006). All guides were required to have a key or other structured access method, which are detailed in Tables 1 and 2; Figure 1. Tree guides were required to have a section specific to winter identification. iOS apps were used on Apple iPod Touch 16 GB (4th Generation) devices. The apps have since been updated (latest versions are 2015), but there are no noticeable changes to the identification keys.
Several guides with text-based keys and extensive species coverage (Rose et al. (2006); Streeter et al. (2010); Blamey, Fitter, and Fitter (2013) were excluded due to their requirement for sound knowledge of botanical terminology. In our experience (also Goulder and Scott (2006), beginners find such guides difficult to use without extended field tuition.

Plant specimens

The lead author undertook a survey of each taxon in the college grounds and randomly selected three groups of suitable species, with no repetitions. There were six species per group for wildflowers, but only five for winter tree trials, due to limited availability. Species deemed unsuitable were as follows: species with sparse populations; species considered too challenging for beginners, e.g. *Castanea sativa*; species with flowers that closed or dropped petals rapidly once cut e.g. *Cardamine hirsuta* and *Veronica persica*. Species were also required to feature in all three relevant identification media.

Table 1. Wildflower and winter tree field guides and access method for identification.

Guide and author	No. species	Primary access method
AIDGAP Winter Trees: A photographic guide to common trees and shrubs (Price and Bersweden 2014)	36	*Structure browsing* – common species grouped by bud configuration, accompanied by summary of distinguishing characteristics, colour photograph and location in the book
Collins Complete Guide to British Trees (Sterry 2007)	47	*Structure browsing* – common species grouped by habitat, accompanied by summary of distinguishing characteristics and colour picture; book also has section of bark photographs and characteristics
Collins Complete Guide to British Wild Flowers (Sterry 2006)	1100	*Structure browsing* – common plant families grouped by flower shape and number of petals, accompanied by summary of shared characteristics, photograph and location in the book
iOS App – WildFlowerId (Isoperla 2013)	214	*Multi-access key* based on 10 characters; plant families are subsequently displayed with percentages that indicate how closely that family matches the selected character attributes
iOS App – WinterTreeId (Isoperla 2011)	68	*Multi-access key* based on 9 characters; plant families are subsequently displayed with percentages that indicate how closely that family matches the selected character attributes
The Wild Flowers of Britain and Ireland (Coates 2008)	500	*Polychotomous key* based on 4 characters, which then directs the user to the relevant section of the book via a character matrix

Table 2. A comparison of % of new wild flower and tree species correctly identified using different identification media.

Identification method	Mean % accuracy rate	Standard deviation
Wild flowers		
Isoperla (2013)	40.82	24.92
Sterry (2006)	35.03	21.76
Coates (2008)	29.39	18.89
Trees		
Price and Bersweden (2014)	65.43	26.02
Sterry (2007)	65.19	25.83
Isoperla (2011)	50.05	28.49

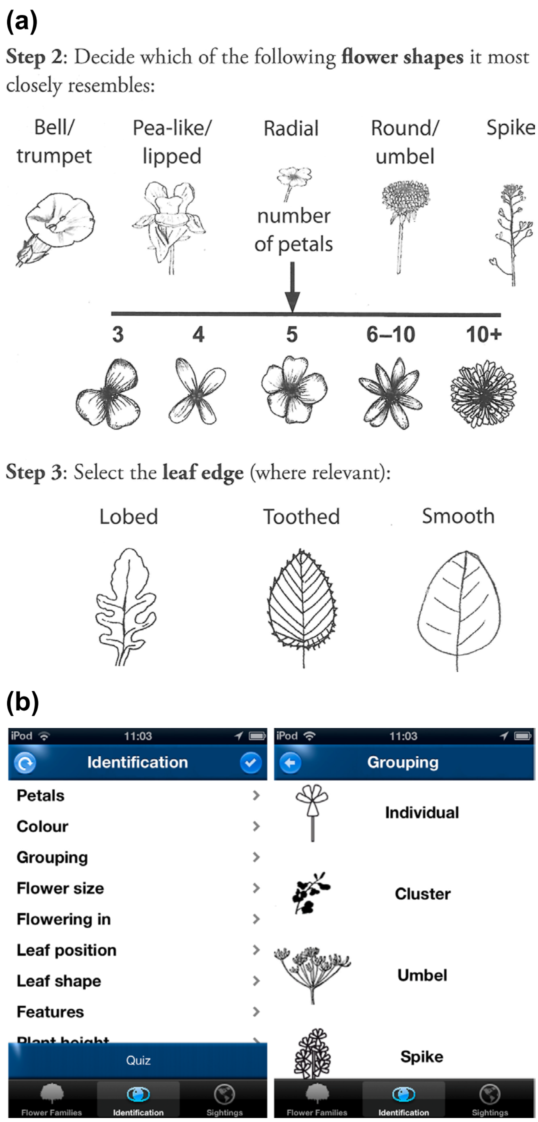

Figure 1. Excerpts from field guides used in trials, showing details of access methods. (a) The Wild Flowers of Britain and Ireland (Coates 2008). (b) iOS app – WildFlowerId (Isoperla 2013). (c) AIDGAP Winter Trees: A photographic guide to common trees and shrubs (Price and Bersweden 2014). (d) iOS app – WinterTreeId (Isoperla 2011).

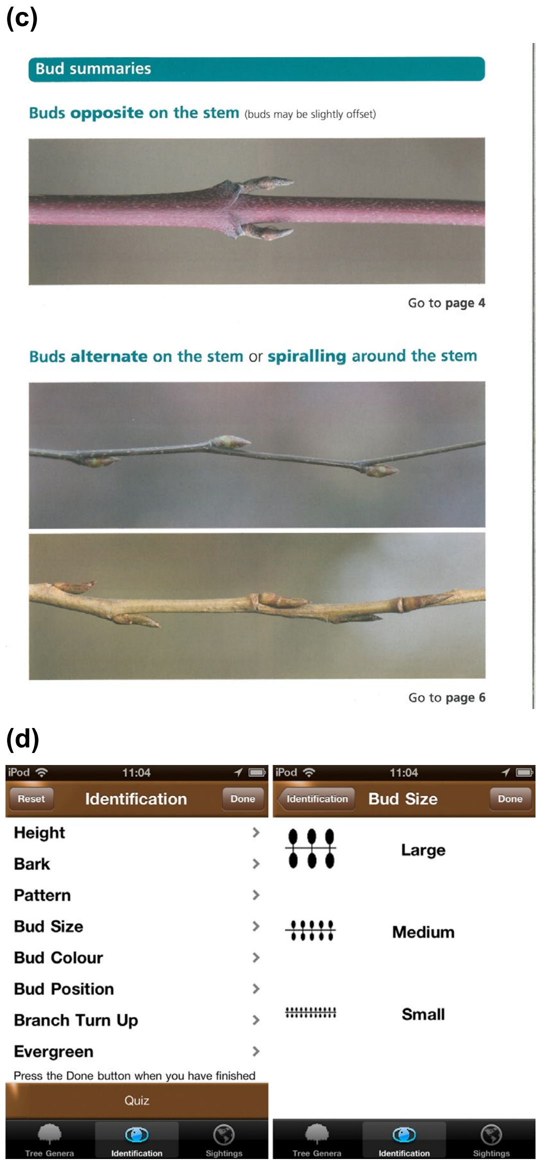

Figure 1. (*Continued*)

Wild flower specimens were harvested immediately prior to each event, whilst twig specimens were harvested prior to the three events and stored in a refrigerator for the two-week duration. Wild flower specimens were presented in a plain glass vessel in trials, to prevent wilting. Specimens had full stems and leaves wherever possible, with basal leaves or rosettes supplied in corresponding numbered Petri dishes otherwise. Winter twig specimens were presented in a white specimen tray, with accompanying colour photographs of the winter tree silhouette; the branch silhouette and trunk bark (Figure 2).

Identification events

Three half-day wild flower events were held during September and October 2013 and three winter tree events in February 2014. Laboratory and classroom venues in Plymouth and South Devon were

Figure 2. Example of specimen box for winter tree trial.

used, with suitable habitats nearby for informal field observation of species following trials. Trials were held indoors because of the difficulty in ensuring controlled conditions in the field environment. Data collected in a pilot study (April 2013) were of low quality because participants were unable to locate flagged specimens, shared results or could not work comfortably due to heavy rain. Events were publicised to undergraduates at Plymouth University, public media and local environmental organisations (e.g. OPAL, Devon Wildlife Trust). Publicity specified that events were aimed at people with little or no prior experience of identifying wild flowers or trees in winter respectively. Twenty-four people (mean age 42 years) attended wild flower events and 37 people (mean age 40 years) attended winter tree events. The lead author and a contracted ecology tutor were responsible for all event delivery.

Each event comprised an introduction, three consecutive identification trials, completion of a questionnaire and 'post trial' feedback and discussion. A different combination of identification medium (book or iPod app) and plant group was used for each trial and each event. Participants were randomly assigned to an identification medium on arrival and completed an ethics consent form. The 15 min instruction covered keys, general morphology of focal plant group, use of a hand lens and a demonstration of each identification medium, using a test species. An iPad was used for the demonstration of the apps to facilitate viewing by the group. To test for prior species knowledge, participants were asked to write the common name of any species they knew already on a form prior to the identification trial.

For each trial, participants were provided with a set of numbered specimens, recording sheet, hand lens and identification medium. The iPods were accompanied by an instruction sheet, reiterating the initial instruction. Participants were required to complete the exercise without conferring and to enter identifications on a recording sheet. During the activities, the instructor provided help and encouragement to participants, as well as monitoring participants' progress and responding to any issues that arose. Participants rotated around identification trials, each 25 min. Following identification trials participants completed questionnaires, requiring the respondent to state favourite and least-favourite identification medium and complete four open questions about the user experience.

The session concluded with feedback and instruction on the focal species, including a field walk where weather and time allowed.

Data analysis

All randomised operations were conducted using number sets obtained from a random number generating website. Recording sheets were scored as follows: one point per correct species identification and half a point for correct species genus. Identification accuracy was defined as the number of new species correctly identified and expressed as a percentage of total number of new species identified. Questionnaires were encoded by categorising and quantifying similar comments. A Related Samples Wilcoxon Signed Rank test was used to test the null hypotheses that there was no difference in % of new species correctly identified using different identification media (identification accuracy). Independent Kruskal-Wallis tests were used to test the null hypothesis that identification medium preference did not affect identification accuracy. These statistical tests were chosen because some of the variables violated parametric test assumptions. All statistical analyses were produced using SPSS 21.

Results – wild flower trials

Effectiveness

Identification accuracy (% of new species correctly identified) was highest for Isoperla (2013), followed by Sterry (2006) and Coates (2008) (Table 2). Related Samples Wilcoxon Signed Rank tests identified significant differences in identification accuracy between Isoperla (2013) and Coates (2008) at the 5% confidence level ($p = 0.028$), but no significant differences between Isoperla (2013) and Sterry (2006) ($p = 0.187$) or Sterry (2006) or Coates (2008) (0.586).

Existing knowledge was low; the mean number of species known prior to the identification exercise was 0.84 (standard deviation 0.89). Genus was more commonly known than species; for example, 41.67% of participants recorded 'bindweed' for *Calystegia sepium*, 29.17% plantain for *Plantago lanceolata* and 20.83% 'mallow' for *Malva moschata*. Only 1 participant correctly identified *Agrostemma githago* and *Hypochaeris radicata*, whilst no participants knew *Solanum nigrum* or *Chrysanthemum sigutum*.

Satisfaction

The most popular guide was Isoperla (2013) and the least popular was Sterry (2006) (Table 3). The 24 participants were asked to explain the main reasons for their preferences. For Isoperla (2013), more than a third of participants (nine) replied that it was easy to use, whilst six participants stated that it allowed for rapid identification. Five participants stated that the photographs to aid identification were helpful in Isoperla's guide. For Coates (2008), seven participants replied that the guide had a useful key. Half the participants (12) stated that the key in Sterry (2006) was either confusing or unusable, with many adding that consequently they resorted to browsing through the book.

Table 3. Participants' preferences for wild flower and tree identification media.

Identification media	% Participants identifying as favourite	% Participants identifying as least favourite
Wild flowers		
Isoperla (2013)	75.00	0
Coates (2008)	25.00	18.75
Sterry (2006)	0	81.25
Trees		
Price and Bersweden (2014)	64.86	10.81
Sterry (2007)	29.73	32.43
Isoperla (2011)	5.41	56.76

Participants were asked whether they preferred using an iPod app or printed guide for species identification, and reasons for their choices. 39% preferred printed guides, 39% preferred apps and 22% liked both equally or would use both in tandem. The most common reasons for preferring printed guides is because they were easier to browse than iPods (easier to view different information simultaneously) or because the respondent disliked new technology; the reason for preferring iPod apps was because they were more portable or convenient than books. Ninety-six per centof users had never used an 'identification app' before, whilst 45% had never used a plant identification guide of any kind.

Efficiency

Isoperla's guide was the most efficient since the majority (two-thirds) of participants required 15 min (to nearest minute) to complete the identification exercise. Coates (2008) required 20 min for a majority to complete the exercise, whilst Sterry (2006) required 25 min. The written feedback summarised in the previous section suggests that Isoperla's guide was most efficient because it was easy and rapid to use, whilst Sterry's guide was least efficient because the key was confusing, or unusable, and encouraged a reliance on browsing.

Results – winter tree trials

Effectiveness

Identification accuracy (% of new species correctly identified) was highest for Price and Bersweden (2014), followed by Sterry (2007) and Isoperla (2011) (Table 2). Related Samples Wilcoxon Signed Rank tests identified significant differences in identification accuracy between Isoperla (2011) and Price and Bersweden (2014) and Isoperla (2011) and Sterry (2006) at the 5% confidence level ($p = 0.032$ and 0.047, respectively). There was no significant difference in identification accuracy between Sterry (2007) and Price and Bersweden (2014) ($p = 0.510$).

Existing knowledge was low; the mean number of species known prior to the identification exercise was 0.70 (standard deviation 1.18). The most commonly known species were *Fraxinus excelsior* (45.95% of participants), *Aesculus hippocastanum* (29.73%) and *Corylus avellana* (27.03%). The least known species were *Platanus acerifolia* (5.45%), *Sorbus aucuparia* (0%) and *Tilia cordata* (0%).

Satisfaction

The most popular guide was Price and Bersweden (2014) and the least popular was Isoperla (2011) (Table 3). The 37 participants were asked to explain the main reasons for their ranking choices in the written feedback. Half the participants (17) responded that Price and Bersweden's guide had a clear or user-friendly format, whilst seven participants stated that it was easy to navigate and five that it had a quick, easy key. Eleven participants described the guide as having excellent or good quality close-up photographs and nine people that the guide was comprehensive or detailed. Many participants were critical of the character states in the Isoperla key. Eleven described character states, particularly tree heights and bud lengths, as ambiguous or subjective. Six participants thought that the bud colour categories did not match the actual buds and six participants felt that there were insufficient character states to allow a beginner to identify the species. A third of participants stated that the key was difficult to navigate, confusing or contained inaccuracies. In contrast, six people found the key easy to use, fun or efficient. A quarter of participants (nine) wrote for Sterry's guide that it was not detailed enough to identify trees in winter. Four participants considered the twig illustrations to be poor quality and four participants liked this guide for the detailed species descriptions.

Participants were asked whether they preferred using an iPod app or printed guide for species identification, and reasons for their choices. Sixty-two per cent preferred printed guides, 24% iPod apps and 14% that they liked both equally or would use both in tandem. Fourteen people preferred iPod apps because they were more portable or convenient than books. Seven people stated that printed guides were easier to browse than iPods (easier to view different information simultaneously), whilst five people considered the iPod was difficult to read because it was too small or light reflected off the surface. Four people described books as being more reliable, because iPods needed charging, or the battery might go flat in the field. Ninety per cent of users had never used an 'identification app' before.

Efficiency

Sterry's and Isoperla's guides were equally efficient, taking 15 min for the majority (two-thirds) of participants to complete the identification exercise (to nearest minute), whilst Price and Bersweden's guide required 25 min for completion of the exercise. The written feedback summarised in the previous section suggests user satisfaction was not affected by identification efficiency, since the most popular guide was also the most time-consuming to use.

Discussion

Field guide usability

Identification accuracy was significantly higher for wildflowers using the iOS app than the two guide books, but significantly lower for deciduous trees. User preference followed a similar pattern. These results demonstrate that the design and quality of identification method is more important than its presentation format. Both iOS apps (Isoperla 2011, 2013) use multi-access keys with clearly labelled navigation stages, allowing easy back-tracking to previous stages, and a summary of the character states selected is displayed and updated during identification, as recommended by Farr (2006). Apps use Isoperla's 'KUSAM' system ('keying using scored attribute method of species identification'), which weights characters according to diagnostic value (Isoperla 2013). The apps allow for comparisons between species and, once a species is selected, a species description with multiple images is available to the user.

The difference lies in the design of character states, which were found to be user friendly for the 'wild flowers' app, but confusing and subjective for the 'winter trees' app. Users considered tree height and bud length character states to be ambiguous, because these were categorised by 'small, medium and 'large', instead of unitised size thresholds (e.g. <10 m, 10 – 20 m, >20 m). For bud colour, the primary colours offered were found to be difficult to match to the subtle colours of some buds, particularly for brown, purple and red hues. Some of the diagrams used for characters were found to be too simplistic and confusing (unlike the 'wildflower' app, which used naturalistic character outlines). Any drawings or diagrams used in keys should not be overly simplistic, as this will confuse novices (Kirchhoff et al. 2011). These authors also recommend using graduated colour swatches instead of single-colour blocks to illustrate colour-based characters, to depict the variation encountered.

Both printed winter tree guides (Sterry 2007; Price and Bersweden 2014) are based on structured browsing, where users browse illustrated winter twig descriptions, grouped by habitat or bud position. Drinkwater (2009) stated that browsing is most effective when the total number of species in a guide is low (<100), which may explain why this access method is more effective for winter trees than wild flowers. The structured browsing access method in the wildflower guide by Sterry (2006), based on illustrated descriptions of plant families grouped by flower structure, was not popular with users. This method worked for species from families with low variation in flower structure, or species that resembled the sample photograph for that family, e.g. Fabaceae (legume family) and Rosaceae (rose family).

Hawthorne, Cable, and Marshall (2014) considered image browsing to be a more effective access method for novices than diagnostic keys. In experimental trials, identification accuracy was 70–95% for identification based on image browsing and was not significantly different to identification using basic keys, except for difficult-to-identify species groups. Randler and Zehender (2006) observed that image browsing does not promote taxonomic learning, since the user's attention is not guided to diagnostic characters. The systematic, analytical nature of species identification using keys is useful training for science students (Lawrence and Hawthorne 2006). The structured browsing method in Price and Bersweden does promote taxonomic learning as images are annotated to draw attention to diagnostic characters.

There was no significant difference between identification accuracy for printed winter tree guides (Sterry 2007; Price and Bersweden 2014), but user preference was substantially higher for Price and Bersweden. Users found the guide easy to navigate, mainly due to its large number of annotated close-up photos. The guide complies with Leggett and Kirchoff's (2011) best practice guidelines, which recommend the use of high-quality colour images on non-distracting backgrounds (e.g. black or white). Images should be to a standard format, for example plants in similar positions or a similar level of detail, to facilitate comparisons. Where photographs are used, multiple examples should be used to illustrate characters (in keys) and species, so that the user appreciates the extent of natural variation. An advantage of electronic guides is their capacity to display lots of images, as they are not spatially restricted like printed guides (Farr 2006). The iOS apps (Isoperla 2011, 2013) display multiple images, both of the whole plant and close-up details of flowers, stems, bark and leaves.

Colour illustrations were found to be as effective as photographs in field guides, in a study by Hawthorne, Cable, and Marshall (2014), although more expensive to produce. The artist is able to depict a specimen to best advantage, accentuating the most important characters (Leggett and Kirchoff 2011). In the wildflower trials, identification accuracy was lowest for the guide by Coates (2008). Authors believe this was due to image quality, which many users criticised verbally during wildflower trials. Users noticed that paintings in Coates were inaccurate for some species, e.g. *Cirsium vulgare* and *Epilobium angustifolium*, and found the colour swatches in the 'flower colour' character misleading for pink and purple specimens.

Usability of mobile computers compared to field guide books

The majority of participants had not used a mobile computer for species identification before. Participants' preferred identification medium following trials was directly influenced by their experiences with the novel technology. In wildflower trials, equal numbers stated a preference for computers and guides books; whilst in winter tree trials, a minority preferred computers. A third of all participants considered the main advantages of mobile computers to be their portability and convenience compared to books. Not only is a mobile computer lighter than all but the slimmest identification guides, but it allows multiple identification guides to be stored in one place. With mobile computers rapidly taking the place of diaries and phones, owners carry their devices at all times, meaning that identification guides are always to hand (Wang, Wiesemes, and Gibbons 2012). Mobile computers do not have the spatial constraints of a guide book, although the volume of information in an app may affect navigability and ease of use.

Many people preferred the navigability of a printed resource to the computer. A feedback comment that captured the general sentiment was: 'you cannot see what is "behind the screen" with an iPod'. Other reservations about computers included the size or reflective nature of the screen, the battery power of the device and reluctance to learn a new technology, which is comparable to user experiences in Ruchter, Klar, and Geiger (2010). The latest generation of iPhones are slightly larger than iPods, with improved screen quality, so up-to-date devices would be easier to use. De Vaugelas et al. (2011) suggested incorporating some of the factual information in an electronic field guide as audio content, thus addressing the difficulty of reading text on a small device in the field. A small number of users stated that they would like to use both printed and electronic resources in tandem and the value of combining the different strengths of identification media, rather than relying on a single guide, is not to be underestimated.

The mean age of participant in this study was 40 and 42 years for wildflower and winter tree trials, respectively, and a younger target audience may have shown a stronger preference for electronic devices (Donoso and Calvi 2008; Ruchter, Klar, and Geiger 2010). Nonetheless, the sample population is a fair representation of the demographic attracted to botanical identification, so its value should not be disregarded. Electronic media are proven to be a highly effective way of engaging young people in environmental education (e.g. Lai et al. 2007; Ruchter, Klar, and Geiger 2010). But digital learning in an educational setting is hindered by the cost of mobile computers, durability and speed at which hardware and applications become outmoded (Tarkus, Maxl, and Kittl 2010; Stagg, Donkin, and Smith 2014). Increasingly, schools are allowing students to use personal devices for classroom learning, as one solution to institutional lack of IT resources (Traxler 2010). Apps are more easily updated than printed resources, as the regular free upgrades to Isoperla wildlife apps demonstrate (Isoperla 2015). Isoperla apps feature interactive quizzes, allowing for self-testing on the species learnt, and the latest version has an automatic recognition feature for leaf shape. Geo-located photos with comments may be shared with online user communities, e.g. iSpot (www.ispotnature.org). Mobile computers have become an important tool in citizen science surveys (e.g. Silvertown 2009) and as a navigational tool for botanical gardens (Ruchter, Klar, and Geiger 2010; Schaal, Grübmeyer, and Matt 2012).

Educational value of botanical identification

Species identification encourages participants to view the plant as a whole organism and engage in close observation, which is proven to enhance appreciation of plants (Nyberg and Sanders 2014). As a self-regulated learning activity, species identification allows the learner to develop their own learning strategies and improves motivation compared to teacher-led biology exercises (Donoso and Calvi 2008). There is a need for more learning about biodiversity in informal contexts, since students learn more spontaneously and with less effort than in formal ones (Donoso and Calvi 2008).

A field guide has two functions: to enable the user to make a positive identification and provide information about the species, e.g. ecology, distribution or uses (Scharf 2009). This study focused on the latter but information content will influence the level of botanical interest aroused in the user (Silva et al. 2011). Inclusion of applied aspects, for example, plant edible or medicinal uses, is considered particularly valuable for engaging novices (Silva et al. 2011).

Conclusion

Overall design and quality of a field guide influenced usability more than the user interface in this study. The iOS app for wildflower identification had higher usability than the iOS app for winter trees, due to quality of character states. Structured browsing was proven to be an effective access method for winter trees and quality of images was an important issue for all guides used in the study. Most users preferred the navigability of a printed guide, although the portability and convenience of the mobile computer was attractive. A younger sample population is expected to show a stronger preference for mobile computers, which could be powerful engagement tools for a younger audience.

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A comparison of descriptive writing and drawing of plants for the development of adult novices' botanical knowledge

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ABSTRACT
Scientific drawing and writing are critical to the development of observational and recording skills in biology. However, it is unclear how the process of drawing and writing contribute to the learning of plant taxonomy. In the present study, 41 adult botanical novices studied a suite of UK native plant species using two methods: labelled drawing and descriptive writing. Tests of species identification and recognition of morphological characteristics indicated that both methods were equally effective at improving species identification. However, drawing captured significantly more morphological information about all study species than writing and was preferred by participants. The quality of drawn and written work was also evaluated and educational implications arising from these are discussed.

KEYWORDS
Species identification; botany; biological drawing; taxonomy

Introduction

The study of biology requires careful observation and recording skills which rely on both writing and drawing (Dempsey and Betz 2001; Ainsworth, Prain, and Tytler 2011). Detailed visual observation is particularly important for plants as they lack the auditory and behavioural cues typical of animals. Plants are an ideal species group for learning observational and descriptive skills since they are sessile and a variety of species are available in most urban environments throughout the year (Dempsey and Betz 2001; Stagg and Donkin 2013).

In plant taxonomy, published florae, field guides and field journals are composed of written descriptions and illustrations of species. Botanical illustration was developed in the seventeenth and eighteenth centuries for the recording of 'type' specimens (Babaian and Twigg 2011), although interestingly, Linnaeus, the founder of modern taxonomy, was intimidated by drawing and relied on written descriptions in his pioneering works on systematics (Reeds 2004). Botanical illustration has not diminished in the era of digital photography. Hawthorne, Cable, and Marshall (2014) showed that colour illustrations can be as effective as photographs for field identification of plants. Leggett and Kirchoff (2011) and Dempsey and Betz (2001) noted the advantages of illustration over photography for presenting the morphological complexity of plants and accentuating the most important characters for identification.

Drawing in biology develops students' observational skills by engaging the learner in close, detailed study of the focal organism (Dempsey and Betz 2001; Baldwin and Crawford 2010; Babaian and Twigg 2011). For example, Baldwin and Crawford found that students developed a greater awareness

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of plant morphology and its relevance to function through drawing. Observing and drawing plants is a learner-centred method of building botanical knowledge with minimal reliance on information transmission.

Although scientific drawing is a regular component of biology classes from primary through to university level, little attention is given to the teaching and learning of drawing as a skill (Gan 2008; Ainsworth, Baldwin and Crawford 2010; Ainsworth, Prain, and Tytler 2011; Quillin and Thomas 2015). Not surprisingly, students at all levels find biological drawing to be daunting (Dempsey and Betz 2001; Baldwin and Crawford 2010). Science students may also be intimidated by drawing because it requires such different mental processes than other practices they encounter in their education (Matern and Feliciano 2000). However, Quillin and Thomas (2015) and Van Meter and Garner (2005) have argued that promoting drawing in science may have positive effects on attitudes, levels of interest, and feelings of self-efficacy.

Despite its central role as a communication tool, there has been little systematic study of how drawing might influence learning (Van Meter and Garner 2005), although more recent studies have demonstrated that drawing benefited learning of visuo-spatial information in physics and chemistry to a greater extent than other strategies (Akaygun and Jones 2014; Gagnier et al. 2017; Scheiter, Schleinschok, and Ainsworth 2017). There are particularly few empirical studies on the role of drawing in taxonomy. Wilson and Bradbury (2016) showed that children's knowledge about a plant species' structure and function improved as a result of producing drawings and written descriptions of the plant. Matern and Feliciano (2000) found that introducing a journal assignment, in which students drew and wrote about the study species, improved exam performance and increased student enjoyment in an undergraduate fish taxonomy class. Alkaslassy and O'Day (2002) found that undergraduate students enrolled in a biology drawing course actually performed worse than other students in the subsequent biology module, although they noted that the drawing course may have attracted the academically weaker students.

Gan (2008) and Van Meter and Garner (2005) suggest that producing labelled drawings may assist memorisation of the focal material. It is well accepted that memory retrieval benefits considerably from the use of both visual and non-visual representation (Paivio 1971; Clark and Paivio 1991; Mayer 2002). Van Meter and Garner note that constructing knowledge through drawing and writing, as opposed to writing alone, should convey these same advantages. Drawing involves the creation of an internal mental model which is then transferred to the external visual representation on paper (Leutner, Leopold, and Sumfleth 2009; Quillin and Thomas 2015). Scheiter, Schleinschok and Ainsworth and Gagnier et al. attributed the pedagogic advantage of drawing to the active learning associated with the activity. In the first study, learners produced a drawing from a visuo-spatial concept described in words; in the second they produced a drawing from a three-dimensional object. Authors proposed that the process of having to transform the focal material into another form promoted deeper learning and the creation of stronger mental models as a result. The physical act of drawing may also contribute to memorisation, according to embodied cognition, the theory that learning is grounded in sensory-motor processes as well as mental processes in the brain. Kiefer and Trumpp (2012) discussed how handwriting improved letter recognition and reading performance to a greater extent than typewriting, which they attributed to the rich sensorial experience and motor activity of writing with a pen.

A contrary view offered by Quillin and Thomas is that drawing may impede learning. In accord with cognitive load theory (Sweller 1988), Quillin and Thomas hypothesised that the mental effort of creating a drawing distracts from the coding of information, particularly if the learner is not experienced or confident with drawing. Consistent with this, Leutner, Leopold and Sumfleth found that children who focused solely on creating a mental model after reading a science text performed better in the subsequent test than children who focused on both mental model creation and a drawing. Given that drawing skills are neglected in science, one might expect that a drawing activity will pose a greater cognitive load than a writing activity.

The present study examined the acquisition of botanical knowledge by adult novices engaged in a descriptive writing and labelled drawing activity. The two types of activities were compared on the extent to which they improved plant identification skills and the recognition of diagnostic characters in the focal species. Participants' drawings and written descriptions were also evaluated; learner-generated drawings are proven to reveal learners' perceptions and understanding of the study material (Gan 2008; Ainsworth, Prain, and Tytler 2011; Quillin and Thomas 2015). Research questions are: do novices observe and record more diagnostic characters through labelled drawings or written descriptions? What is the quality of novices' labelled drawings? What kind of terms do novices use to describe plant species? What types of diagnostic characters are depicted in drawings and written descriptions of species?

Method

Species

A variety of native species were selected from habitats close to the event venues, avoiding any identified as common knowledge (Stagg and Donkin 2013, 2016). The selection comprised two groups of four *study* species, each with a corresponding *look-alike* species (Table 1). The look-alike species were not included in the learning activities but served as foils in the pre- and post–activity identification tests. Their inclusion was designed to test participants' ability to differentiate between the study species and morphologically similar species. Specimens were harvested immediately prior to each event; whole plant specimens were used for all species, apart from the two tree species where mature stem cuttings were taken. Specimens were presented in plain glass vessels to prevent wilting.

Experimental trials

Five half-day wildflower events were held during October 2015 in laboratory and classroom venues in South Devon. The aim of the events was to introduce beginners to autumn-flowering species common to the local area, as part of nature engagement project OPAL (www.opalexplorenature.org). The events were targeted at first-year students enrolled on relevant programmes, with the aim of engaging students in future field events and bio-monitoring surveys organised by OPAL. Attendance did not count towards course credit and events were held during study time and weekends. Indoor venues were used due to seasonal weather conditions and the difficulty of conducting controlled trials in the field environment but many participants subsequently participated in field events as part of the same project. Event announcements were circulated by email to students enrolled on relevant courses by programme adminstrators or managers. 26 participants attended events from biological science degree programmes at Plymouth University (n = 26) and 17 students from degree programmes in applied ecology at Schumacher College . In order to ensure the attendance of only botanical novices, the event announcement stated that participants should not be able to identify more than twenty common native plants. The lead author (an ecology lecturer) and an ecology tutor (affiliated to the region's Field Studies Centre) delivered the event. The experimental trial comprised a pre-activity identification test of 16 plant species, general instruction, two learner-centred activities (descriptive writing, labelled

Table 1. Plant species used in learning activities and identification tests.

Plant Group 1: Study species	Look-alike species
Grey willow *(Salix cinerea)*	Blackthorn *(Prunus spinosa)*
Cat's-ear *(Hypochaeris radicata)*	Rough hawkbit *(Leontodon hispidus)*
Common spearwort *(Ranunculus flammula)*	Meadow buttercup *(Ranunculus acris)*
Devil's-bit scabious *(Succisa pratensis)*	Field scabious *(Scabiosa columbaria)*
Plant group 2: Study species	Look-alike species
English Elm *(Ulmus minor)*	Small-leaved lime *(Tilia cordata)*
Water pepper *(Persicaria hydropiper)*	Redshanks *(Persicaria maculosa)*
Common toadflax *(Linaria vulgaris)*	Ivy-leaved toadflax *(Cymbalaria muralis)*
Fox and cubs *(Pilosella aurantiaca)*	Bristly oxtongue *(Helminthotheca echioides)*

drawing), and post-activity identification and morphology tests and feedback questionnaire. Events also included a presentation and discussion about identifying, drawing and describing wild flowers and an introduction to identification resources for beginners. Three events included an opportunity to observe some of the study species growing in habitats adjacent to the event venue.

Different sets of specimens were used for the identification tests and the learning activities. For the tests, the specimens were presented in a numbered row for inspection with the order randomised for each test. In the pre-test, participants were asked to write the common name of any species they knew on the test sheet. In the post-test, participants were asked to write the common name for any study species they recognised next to the corresponding number on the test sheet; for look-alike species, they were asked to simply write 'look-alike' in the space provided. The identification test was followed by a morphology test designed to assess recognition of diagnostic characters which comprised eight 'true or false' questions, one for each study species (Figure 1). Finally, a feedback questionnaire measured participants' attitudes toward the activities using three questions with Likert-scale ratings and one open-ended question (questions are listed in the results section).

Prior to the learning activities, a 20 min general instruction provided brief guidance on plant anatomy, specimen observation, use of a hand lens, descriptive writing, and labelled drawing. Participants were provided with a booklet which reiterated verbal instruction. Participants were instructed to observe the plant in detail, including its name, structures and distinctive features, and to produce either a labelled drawing or written description to capture this information. They were reminded to be mindful of the time limit and to aim to capture a full representation of the plant in the time available. Participants were encouraged to be undeterred by drawing ability or botanical knowledge and were advised to create their own terms for unknown morphological features.

Participants used the blank pages and lined pages provided in the instruction booklet for drawing and writing respectively. Each page had a number corresponding to a numbered label placed beside each plant specimen. The label also featured the plant's common name. A 30 cm ruler, hand lens, HB pencil, rubber and sharpener were provided alongside the specimens. Every participant took part in both the descriptive writing and labelled drawing activities. The order of the activities and the plant group assigned to each activity was randomised for each participant. Twenty minutes was allocated to each activity.

The identification and morphology tests were repeated six weeks later, to test reliability (stability) of test data and learning retention. Test sheets were sent to participants by email, accompanied by a photo gallery of test plant species. However, the return rate was too poor for data to be included in this study.

2.

a) Flowers grow in clusters at the top of the stem	True	False
b) The leaves have jagged (toothed) edges	True	False
c) Leaves are equally hairy on both sides	True	False
d) The stem is hairy	True	False

Figure 1. Example of morphology test question for Fox and Cubs (*Pilosella aurantiaca*).

Results

Assessments and evaluations of participant data were conducted by the study authors. All statistical analyses were produced using SPSS 23.

Species identification and morphology tests

In the identification test, one point was awarded per full correct species name. Half a point was awarded for partial species names e.g. 'devil scabious' (devil's-bit scabious), 'elm' (English elm) and 'spearwort' (lesser spearwort). For the pre-activity test, mean number of correctly identified species was 0.31 out of 16 species, with 86% of participants scoring zero. This confirmed that the sample population were novices in botanical identification.

For the post-activity test, paired *t*-tests were used to compare performance in the drawing and writing conditions using a significance level of $\alpha = 0.05$. Look-alike species and study species were scored separately. No significant difference was observed between activity conditions in correct identifications scores for either the study species, $t(42) = 0.37$, $p = 0.71$, or look-alike species, $t(42) = 0.47$, $p = 0.64$. The same was true for the morphology test of the study species, $t(42) = 0.63$, $p = 0.53$ (Table 2).

Because there were no effects of activity, the data was collapsed across conditions and pre- and post-activity tests were compared in order to confirm knowledge gain. Identification of study species was significantly higher in the post-activity test, $t(42) = 7.83$, $p < 0.001$. In summary, although the learning activities succeeded at improving species identification, there was no advantage of one activity over the other on the simple measure of identification accuracy.

Evaluation of drawings and descriptions

Labelled drawings and written descriptions were evaluated using a method developed from Wilson and Bradbury (2016). A list of key diagnostic characters was produced for each study species using three leading botanical field guides (Rose et al. 2006; Streeter et al. 2010; Blamey, Fitter, and Fitter 2013). Each list consisted of between nine and 12 diagnostic characters per species. Each drawing was visually assessed to score the number of diagnostic characters that were clearly discernible in the drawing or accompanying labels or annotations. Each written description was similarly scored for the number of diagnostic characters clearly described in the text (Figures 2 and 3). Correct botanical terminology was not required, as long as the meaning of the term used was clear.

More diagnostic characters were recognisable in drawings than written descriptions for all eight study species (Figure 4). A repeated measures ANOVA confirmed that significantly more characters were produced in the drawing compared to the writing activity, $F(1, 41) = 71.28$, $p < .001$, $\eta_p^2 = 0.635$.

Table 2. Comparison of 'post-test' scores after drawing and writing activities and paired t-test results ($n = 42$).

	Mean test score	Standard deviation	Mean % test score	*t* statistic	Degrees of freedom	Probability value
Species identification ($n = 8$)						
Drawing	2.01	1.10	25.13	0.37	40	0.71
Writing	1.93	1.28	24.13			
'Look-alike' species ($n = 8$)						
Drawing	3.11	1.13	38.88	0.47	40	0.64
Writing	3.02	1.31	37.75			
Morphology ($n = 36$)						
Drawing	8.83	1.92	24.53	−0.63	41	0.53
Writing	9.05	1.99	25.14			

1. Compound flower/flower dandelion-like
2. Flower is yellow
3. Flowers are solitary (i.e. do not grow in clusters)
4. Outer florets are greenish/greyish underneath
5. Flower has scale-like bracts
6. Flower bracts have dark tips/purple-tipped barbs
7. Base of the flower head (involucre) is bell-/cup-shaped
8. Leaves are oblong-lanceolate in shape
9. Leaf margins are wavy-toothed
10. Leaves are hairy/bristly
11. Scale-like bracts on stem
12. Stem is branched

Figure 2. Diagnostic character list for Cat's-ear (*Hypochaeris radicata*).

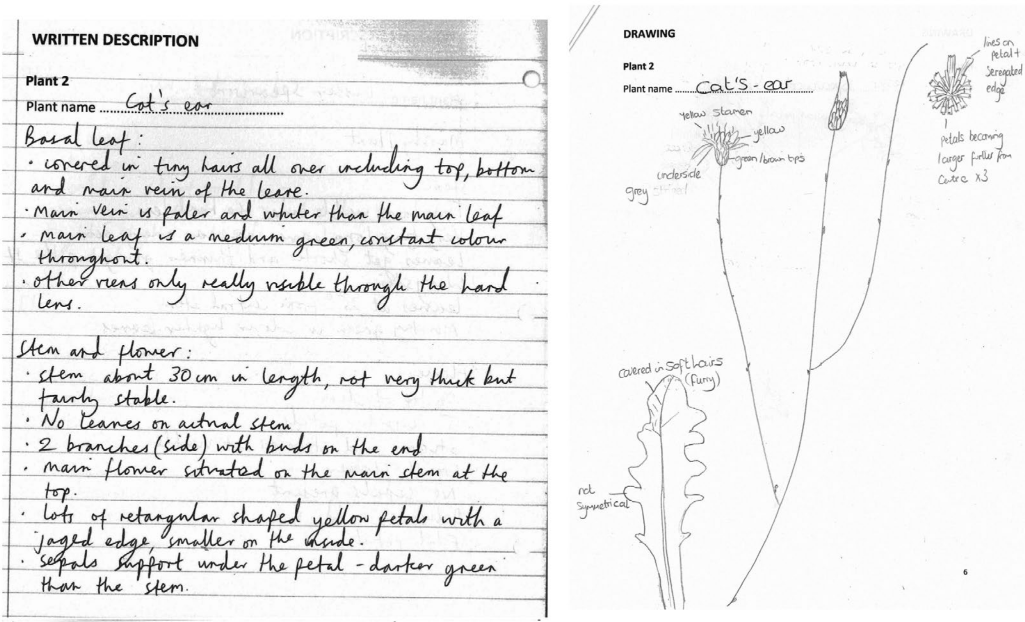

Figure 3. Example of a written description and drawing for Cat's-ear (*Hypochaeris radicata*); assessment scores = 4 and 12 respectively.

Drawings were assessed for scientific accuracy and quality, using the criteria for biological drawings detailed in Oxford, Cambridge and RSA (2015), an 'A' Level guide to biological drawing skills. These criteria were considered to be an appropriate benchmark since most participants would have undertaken 'A' Level biology or an equivalent qualification prior to degree enrolment. The suite of assessment criteria and the number of participants that fulfilled each criterion in their drawings is shown in Figure 5. Krippendorf's $\alpha = 0.86$, which indicates a good level of agreement between the two assessors' scores, for the type of data assessed (De Swert 2012).

The majority of the participants produced drawings that were drawn with a sharp pencil, appropriately positioned on the paper, and with all major structures labelled. Some participants produced drawings that were annotated as well as labelled. Annotations are concise notes describing the structures drawn, whereas labels are just names or phrases for the structures indicated (Oxford, Cambridge and RSA 2015). Approximately half the participants produced drawings with no shading and appropriately

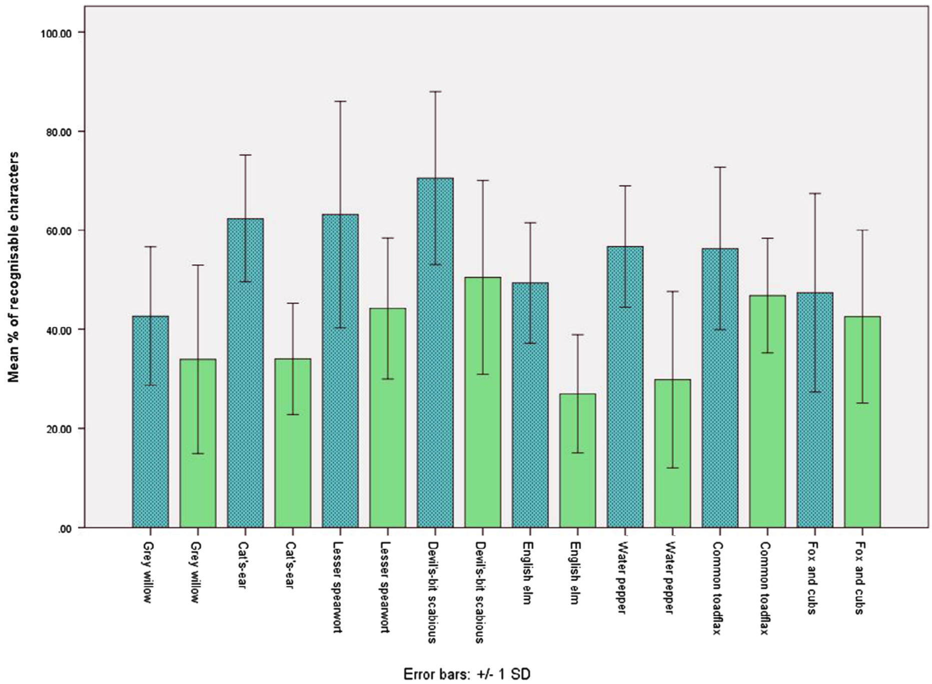

Figure 4. Comparison of the % rate of diagnostic characters identified in drawings and written descriptions (blue/stippling denotes the drawing activity; green/no stippling denotes the writing activity).

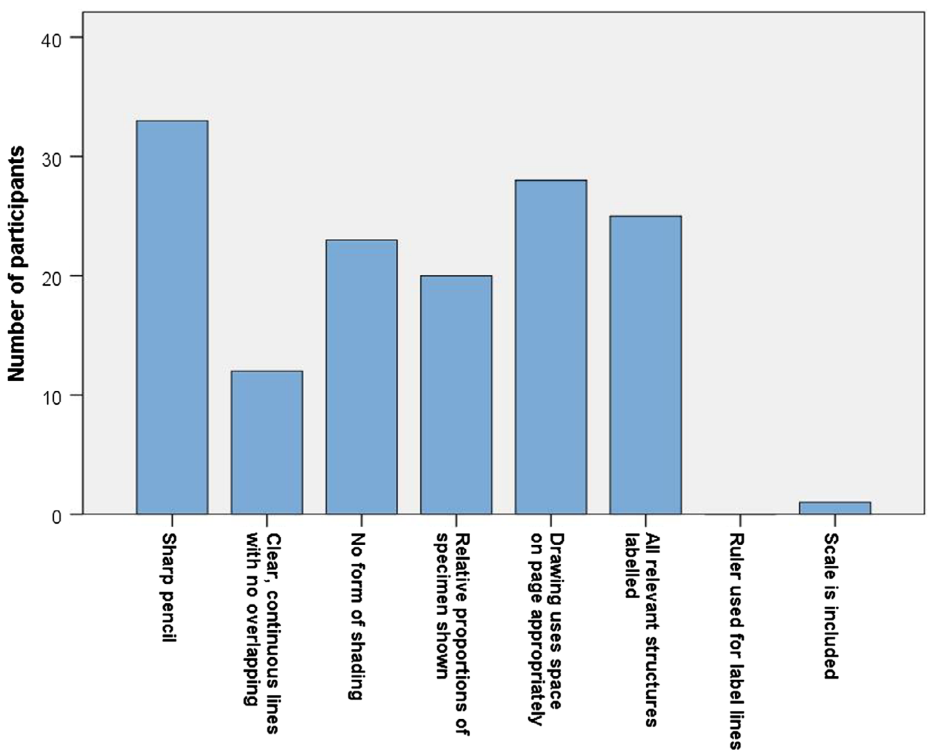

Figure 5. Evaluation of participants' drawings (n = 43).

positioned on the paper. Only a quarter of the participants produced drawings composed of clear, continuous lines with no overlapping. Almost none of the participants used the rulers provided for label lines or denoted scale in the drawings. Examples of participants' drawings are reproduced in Figure 6.

Written descriptions were assessed on the correct use of botanical terms and on the nature of the non-botanical terms employed. Botanical terms were defined as words or phrases listed in the glossaries of the botanical field guides by Rose et al. (2006), Streeter et al. (2010), or Blamey, Fitter, and Fitter (2013). Unlike scientific drawing skills, the knowledge of botanical terminology is not a requirement in 'A' Level biology or equivalent qualifications (e.g. AQA, 2017; Oxford, Cambridge and RSA 2017). However, since all students in this sample will have had experience of biological field identification, it is reasonable to assume that they will have encountered botanical terms to varying extents.

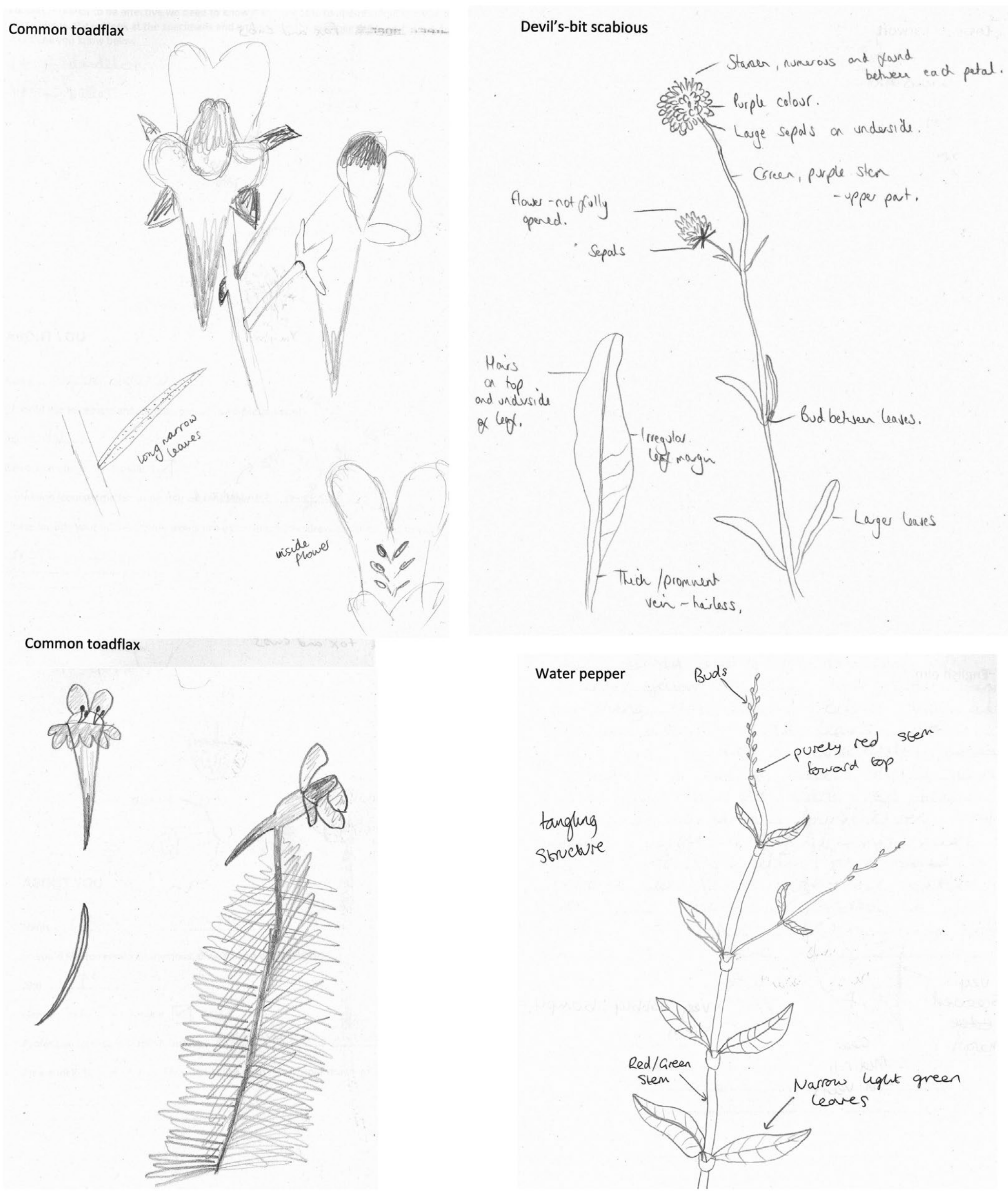

Figure 6. Examples of participants' drawing (drawings with low assessment scores on left; high scores on right).

The majority of participants (90%) used no botanical terms in their written descriptions apart from basic terms for the parts of the flower (e.g. stamen, petal). Participants employed a variety of similes and metaphors to describe plant characters; examples are shown in Figure 7. Flower structures were compared to flowers that were familiar to the participants. Linear leaves were described as 'grass-like', obovate as 'egg-shaped' or 'tear-drop-shaped', whilst lanceolate leaves were described as being shaped like a 'blade' or 'spear'. The wavy-toothed margin of *Hypochaeris radicata* was frequently described as 'rocket-shaped' (rucola).

It was evident from written descriptions that participants had little experience of plant identification. Many participants described characters that were not relevant for identification, typically colour (and colour variation) of stem, leaves and leaf venation, and the consistency of leaves and stems (e.g. thickness, pliability). Only 11% of participants included measurements in their drawings or written descriptions, yet average measurements of plant parts, e.g. plant height and length of flower or leaf, are frequently used as diagnostic characters in identification guides (e.g. Rose et al. 2006). Where participants did include measurements, these were typically irrelevant to diagnosis, for example distance between leaf veins or between branches.

Comparison of types of diagnostic characters

Diagnostic character data from drawings was collated for all 8 species, to investigate why the proportion of characters depicted varied across species (Table 3). The data suggest that the morphology of small, subtle features (e.g. bracts, bud trichomes) are less likely to be represented in drawings than the morphology of entire structures (e.g. leaf, flower), perhaps because they are not detected or are difficult to draw. A similar trend is evident in the data for written descriptions, although some inflorescence characters were also poorly represented in descriptions, suggesting low detection rates, or perhaps they were difficult to describe. We must treat this finding with caution, since data exhibited low sample sizes and high standard deviations. Nonetheless it suggests a valuable line of enquiry for future studies.

Based on this hypothesis, we would expect drawings of species with a high proportion of 'subtle' characters to depict less diagnostic features than for drawings of species with a high proportion of 'obvious' characters' and this is indeed the case. We defined 'subtle' characters as 'shape of leaf base or tip', 'shape or colour of bracts or sepals', 'fine detail relating to hair and colour of specific part of flower' (Table 3). All other characters were defined as 'obvious'. Less than 40% of diagnostic characters were depicted in drawings for the species *Pilosella aurantiaca, Salix cinerea* and *Ulmus minor* (Figure 4) and ratio of 'obvious' to 'subtle' characters was 6:5, 4:3 and 3:2 respectively. In contrast, more than 60% of characters were depicted for *Hypochaeris radicata*, *Succisa pratensis* and *Ranunculus flammula* and ratio of 'obvious' to 'subtle' characters was 9:2, 8:2 and 6:1 respectively.

Participant feedback

The majority of participants (66%) stated that they preferred drawing to note taking. Likert-scale scores suggested that participants found drawing plants more enjoyable and educational than writing descriptions (Table 4). An emerging-theme analysis with no *a priori* categories was applied to the open-ended question about activity preference (Cohen, Manion and Morrison 2007). Dominant themes were that drawing encouraged more detailed observation of the plant and formed better holistic representation than writing (Table 5). However, many participants found it harder to depict details of the plant through drawing and felt limited by their drawing ability and the time available. Some participants found their lack of botanical knowledge to be a constraint in the writing activity.

Discussion

Studying plant samples using labelled drawing and written description improved species identification and recognition of species' diagnostic (morphological) characters. Improvement was modest but

Figure 7. Examples of terms commonly used by participants for describing plant structures.

reasonable given that the participants were novices and this was a single learning opportunity. The drawing and writing activities showed no significant differences in the amount of learning. We observed no special benefit of the use of imagery, but at the same time found that the cognitive load incurred by drawing had no detrimental effect on concurrent learning. Is there any reason, then, to prefer one activity over the other as a way to study plant species? One reason may have to do with affective engagement. Most participants preferred drawing plants to writing about them. Drawing was thought

Table 3. Diagnostic characters for 8 plant species depicted in drawings and written descriptions. Only characters where $n > 2$ are shown.

		Mean % of samples correctly depicting character		Standard deviations	
Diagnostic character	Total	Drawings	Written descriptions	Drawings	Written descriptions
Entire structures					
Leaf hairy	3	87.18	93.33	3.96	8.33
Leaf margin (e.g. crenate, entire)	8	86.11	45.71	11.03	28.52
Leaf shape (e.g. obovate, lanceolate)	9	84.58	48.89	17.31	25.96
Shape of flower	5	78.9	73.67	15.91	18.90
Shape of involucre (structure at base of inflorescence)	7	76.35	21.00	9.55	16.52
Configuration of leaves (e.g. alternate, whorled)	6	68.88	32.00	18.71	22.24
Shape of inflorescence	6	68.52	43.20	23.83	17.20
Colour of flower	6	61.33	75.83	15.94	25.52
Small, subtle features					
Presence of stipules or bracts on stem	3	60.94	38.67	16.25	11.37
Shape of leaf base or tip (e.g. asymmetric at base, tapered at base)	4	55.68	11.67	7.93	13.20
Shape or colour of bracts or sepals	3	42.26	11.67	19.04	11.06
Fine detail relating to hair (e.g. bud sparsely hairy, hair colour)	6	19.68	35.43	16.54	22.99
Colour of a specific part of flower (e.g. anthers, central florets)	3	17.16	33.00	11.49	15.10

Table 4. Responses to six-level Likert-scale questions about drawing and writing activities ('1' = 'strongly disagree', '6' = 'strongly agree').

Statement	Mean response	Standard deviation
Drawing and observing plants was more enjoyable than observing and taking notes about plants	4.1	1.55
Observing and taking notes about plants was more stressful than drawing and observing	2.79	1.24
I felt like I was learning more from drawing and observing plants than observing and taking notes	3.68	1.59

to be the more enjoyable and educational activity. The pedagogical benefits of enjoyment should not be underestimated: enjoyment promotes motivation and interest, which are integral to learning (Ryan and Deci 2000). Enjoyment of science fosters interest in science, and the desire to pursue it further (Ainley and Ainley 2011). A number of authors have proposed that drawing in science deserves a higher profile, for its potential to increase student motivation and engagement in science (Van Meter and Garner 2005; Ainsworth, Prain, and Tytler 2011; Quillin and Thomas 2015).

Drawing showed an advantage in information richness. Participants included substantially more morphological characters in drawings of plants compared to written descriptions, a finding also reported by Wilson and Bradbury (2016). Drawing is invaluable for conveying information that is time consuming or difficult to describe in words (Gan 2008). Akaygun and Jones (2014) and Wilson and

Table 5. Dominant themes (> 6 responses) collated from responses to open-ended question asking participants for feedback about drawing and writing activities.

Theme	Frequency	Examples of comments
Harder to depict the plant in detail with drawing, compared to writing	13	Drawing was good but difficult to add detail Able to get down small characteristics with writing The characteristics are not recorded adequately with drawing Written observation was much easier to record detail
Easier to form a mental image of the plant by drawing it, compared to writing	11	Drawing the characteristics helped me memorise the key features When drawing you're looking closely and repeating it which stays in your head With drawing I could see what I was trying to draw and fit it together with the rest of the image of the plant I was more able to visualise the plant with drawing
My limited drawing ability made it difficult to depict the plant using drawing	9	I'm not very good at sketching so it wasn't as accurate as my written descriptions I'm rubbish at drawing but can describe all my observations thoroughly and in more detail using words I was inhibited by my poor drawing skills
Writing descriptions allowed more time for observation of the plant than drawing	7	With drawing I didn't have enough time…the writing was easier in the time provided Time seemed to go much quicker with drawing…language provided a series of steps, a framework, for summarising much quicker
Drawing encouraged me to focus more deeply on the plant than writing	7	The drawing encouraged me to focus more on each part of the plant Noticed many more features whilst drawing Learned more from drawing - you must look closely at every part
Limited knowledge of botanical terminology was a constraint for writing	6	Many of my descriptions are limited by lack of botanical vocabulary Maybe writing easier if I knew more of the terminology

Bradbury (2016) demonstrated that learning is most effective when children use drawing to describe the configurations and spatial relations between phenomena, making use of writing to describe the accompanying functions or processes.

Interestingly, more than a quarter of participants in this study stated in feedback that it was harder to depict the plant in detail with drawing than with writing, implying that they under-estimated their own drawing skills as a communication tool. Nine of the 43 participants stated that their limited drawing ability was an issue, whereas only six participants mentioned their limited knowledge of botanical terminology.

Drawing is often criticised for being a highly time consuming aspect of taxonomic study (e.g. Coleman 2006) but the present study has demonstrated that rapidly produced drawings are able to capture substantial morphological information. The drawing of specimens will benefit learning to a greater extent than photography because it supports and trains students' observational skills. Alkaslassy and O'Day (2002) found that the most common theme in feedback from biology undergraduates enrolled on a drawing course was that it developed their powers of observation. Baldwin and Crawford (2010) noted that students' awareness of plant structure and variation increased as a result of drawing tuition. Babaian and Twigg (2011) suggested that 'drawing is an amazing tool. It literally 'draws' us into a relationship with what we are attempting to illustrate and allows us to stay in the moment' (page 217). In feedback, about a quarter of the participants said that they found it easier to form a mental image of the plant by drawing it, rather than describing it. People learn to recognise complex objects like plants holistically and drawing a plant would be expected to promote holistic recognition to a greater extent than writing, which encouraged systematic observation of each part of the plant (Kirchoff et al. 2011).

The poor knowledge of botanical identification and terminology in written descriptions might be expected from the botanical novices recruited for the study. However, a contributing factor may be that biology undergraduate and 'A' Level students are known to have a diminished plant identification knowledge compared to 20 or 30 years ago (e.g. Bebbington 2005; Goulder and Scott 2016). Moreover, there has been a decline in biological fieldwork at secondary school level and students have fewer experiences of species identification outside of educational settings . Students are more interested in studying animals than plants to the extent that this has acquired a label, 'plant blindness' (Schussler and Olzak 2008).

Participants were not deterred by lack of botanical knowledge when describing plant specimens and generated an array of similes and metaphors to describe plant characters. Some character descriptions were highly specific and accurate, for example the doubly-serrated leaf margin of *Ulmus minor* was described as 'shaped like chainsaw teeth' by one participant. The glandular trichomes of *Succisa pratensis* were described as 'small black spikes with balls on the end.' It was clear that, although participants were not familiar with certain structures such as stipules and ochreas, they noticed these and attempted to describe them as best they could.

Educational implications

Participants did not possess the full suite of drawing skills that would be expected for biology undergraduates, with many drawings exhibiting shading, broken/overlapping lines or poor proportions of the focal specimen. Like previous authors (e.g. Baldwin and Crawford 2010; Prain and Tytler 2011), the outcome suggests a need for more drawing tuition in biological education. Baldwin and Crawford (2010) found that tuition with a visual arts instructor improved the drawing skills and confidence of undergraduate students enrolled in a plant ecology module. Dempsey and Betz (2001) used an exercise for developing students' observational skills in which students were required to draw the specimen from memory following a period of visual study. The practice both enhances visual representation and provides feedback about what has been learned. Goulder and Scott (2009) noted that open-ended learning, where students choose their own specimens in a field environment for a drawing and identification activity, may provide an even richer experience compared to pre-selected specimens in a laboratory.

In study feedback, it was also evident that many participants had poor confidence or belief in their drawing skills, which highlights the necessity of drawing tuition specific to taxonomy courses, to prevent students shying away from this valuable recording method. In the lead author's experience, students rely heavily on note taking for learning plant species identification in the field and produce drawings only when required to for assessment.

Participants in the study produced a variety of similes and metaphors for describing plant characters, which could form the basis for an introductory activity in beginner botany courses and modules. Novices are known to find botanical terminology off putting and daunting (Jacquemart et al. 2016) and learner-centred activities like these are proven to increase motivation and positive attitudes (McCombs and Whisler 1997). Stople and Björklund (2012) described a method of teaching soil classification by comparing soil textures to those of familiar objects, for example toothpaste or a sandy beach. Learner-generated terms are also valuable for helping to identify and address learners' existing knowledge and perceptions (Wilson and Bradbury 2016).

Participants in the study were more likely to include details relating to entire structures in drawings, compared to small, subtle structures or details of structures. A similar trend was identified in written descriptions, although there were low inclusion rates for some entire structures also. Plants are morphologically complex and this outcome highlights the importance of drawing students' attention to the smaller diagnostic features and repeated practise in the use of a hand lens. Introducing novices to species with easily observed diagnostic features first, before progressing onto the more complex species, may also enhance learning.

Conclusion

Drawing produced a greater depth of information about plant morphology than writing, with no discernible negative effect on learning. Drawing is a more appropriate tool for depicting plant morphology than written descriptions, although writing provided valuable insights into participants' understanding of plant morphology. Students in this study were deficient in scientific drawing skills, suggesting that closer attention to this skillset is required at undergraduate biology level.

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Story of a Seed: educational theatre improves students' comprehension of plant reproduction and attitudes to plants in primary science education

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ABSTRACT

Background: Although plant reproduction is a core subject in school science curricula, botanical topics are typically unpopular with students. Integrating the arts into science subject matter has the potential to increase student interest and understanding. Educational theatre has shown particular promise in this area.
Purpose: The study examined how an interactive theatre performance, where professional actors deliver a performance but invite regular audience participation as a way to promote active learning, benefited both understanding of plant reproduction and attitudes towards plants. Perceptions of the play and the way in which specific elements influenced learning and emotions were examined in detail and placed in a theoretical context.
Sample: Opportunity sampling was used to recruit participants from five public primary schools in Devon, UK. One hundred and forty-four students (aged 9–11 years) participated in the study.
Design and methods: A mixed methods approach was adopted. Quantitative analysis of pre- and post-intervention knowledge tests involved t-tests and repeated measures ANCOVA. Qualitative analysis of semi-structured interviews made use of an emerging theme analysis with *a priori* categories.
Results: Pre- and post-intervention tests indicated an increase in both knowledge of plant reproduction and positive attitudes towards plants. Follow-up interviews identified elements that were particularly beneficial for learning and enjoyment, including the thematic singing, humour, novelty of the play, visual elements and participatory art activities.
Conclusions: This case study demonstrates the potential that an interactive theatre production offers for enhancing appreciation and interest in school science while improving knowledge.

KEYWORDS
Theatre; art; primary science; plant sciences; drama

Introduction

Children enjoy science at primary school level but interest in science diminishes between the ages of 10 and 14 years (Archer et al. 2010; DeWitt et al. 2013). Aspirations to be scientists

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Supplemental data for this article can be accessed here.

are low in children and young people of all ages, particularly girls. Poor scientific literacy among primary school teachers can result in attitudes towards science that contribute to the problem (Van Aalderen-Smeets and Walma van der Molen 2015). Innovative teaching methods are needed to sustain students' interest in science and make it more attractive as a career choice. The integration of the arts into science education promoted by the *STEAM* movement has received growing attention for its potential to increase school students' interest in science as well as to foster creative thinking and practice in STEM disciplines (Sousa and Pilecki 2013). Incorporating art and design, drama and musical composition into the science classroom has been shown to enhance learning and enjoyment (Lerman 2005; Crowther 2012; Hardiman, Rinne, and Yarmolinskaya 2014; Çil 2015).

The use of the dramatic arts as a pedagogical tool is not a new idea. A prominent example of its use in the UK is the Theatre in Education (TIE) movement, initiated by professional theatrical groups in the 1960s (Jackson 2002). TIE and other contemporary theatrical initiatives have placed the emphasis not just on subject-specific concepts but on cultivating creativity and enthusiasm, appreciating the nature of science and learning about science's interactions with society (Ødegaard 2003).

In reviewing a number of drama in science projects, Ødegaard (2003) concluded that educational benefits were mainly in the realm of higher level cognitive (e.g. comprehension, interpretation) and affective skills (e.g. attitudes, confidence, empathy) rather than factual recall. Similarly, Metcalfe et al. (1984) found that the use of drama in chemistry lessons did not increase factual recall but did improve students' ability to explain and apply concepts. Jansson and Aksela (2013) noted that theatrical audiences were impressed less by the science itself and more about the persona and life of the scientist, and by extension the place of science in society. Dorion's (2009) examination of drama use in science classrooms looked at its ability to alter perspectives and promote dialogue and positive affect.

Other studies, however, have shown more direct benefits on learning. Bailey and Watson (1998) found that a drama/role-play exercise improved students' knowledge on a range of ecological concepts. Peleg and Baram-Tsabari (2011) reported that watching a play on the subject of physical chemistry had positive effects not only on affect but on factual knowledge. Students participating in a drama activity about the electrolysis of water exhibited higher knowledge gains than students engaged in a non-drama activity (Saricayir 2010). Drama-based instruction about the states of matter and methods of heat transfer increased knowledge and positive attitudes towards science to a greater extent than a non-drama control group (Abed 2016).

The play produced for the present study, *Story of a Seed*, adopted the medium of interactive theatre where professional actors deliver a performance but invite regular audience participation as a way to promote active learning (Peleg and Baram-Tsabari 2011). The aim of the play was to communicate plant reproduction to children aged 9–11 years. The play was not designed to replace formal classroom instruction but to provide an introduction to the topic, as a way of stimulating student interest and learning. Given previous mixed findings, we were particularly interested in whether the experience would lead to retained knowledge beyond the initial experience.

Plant reproduction is a topic included in primary and secondary curricula in most countries (Schussler and Olzak 2008). In the UK, children are introduced to this topic at the age of 10–11 years (Government Digital Service 2016). Children are required to learn to label the reproductive organs in a diagram of a flower and develop a conceptual understanding of pollination (transfer of pollen to female reproductive organs), fertilisation (fusion of male and female reproductive cells) and seed dispersal (movement or transport of seeds away from the parent plant). In primary schools, pedagogical methods include the dissection and drawing of a flower, investigative work about plant life cycles and a variety of educational games (Link-Pérez and Schussler 2013; Science and Plants for Schools 2016).

The low interest children have in plants is attributed to the phenomenon of 'plant blindness', an inability to notice or value plants in the environment (Schussler and Olzak 2008; Link-Pérez and Schussler 2013). Educational media present plants in a less charismatic light than animals, and instructional methods may fail to foster an interest in plants. Children develop at best a partial understanding of plant reproduction through school science and exhibit misconceptions about the topic. For these reasons, plant reproduction is an ideal subject for piloting a novel engagement activity.

The research questions for the study: (1) How does an interactive theatre performance about plant reproduction influence children's knowledge and attitudes towards plant science? (2) What are children's perceptions of the play and how do specific elements of the play influence learning and emotions?

Theoretical framework

We position theatre as a pedagogical tool that promotes the aims of humanistic science education as proposed by Yoon (2006) and Peleg and Baram-Tsabari (2011) in their studies on educational science theatre. Humanistic perspectives in science have existed for more than 150 years. Their importance in science education is well articulated by Aikenhead (1996, 2006, 2007) and Lemke (2001), who draw attention to the fact that science education is about learning to navigate the culture of science as well as knowledge acquisition, and that culture is often at odds with the subcultures that students occupy outside of school science. To become more accessible, school science needs to share some of the social and cultural characteristics of students' everyday worlds. We suggest that theatre has the power to render school science more accessible through its use of narrative and metaphor, and emotional engagement.

Narrative and metaphor

Theatre is based on a narrative or story, a naturalistic account of connected events (Ødegaard 2003). Narrative does feature in science education but the dominant mode is argumentation: reasoning in support of an idea or theory, the use of formal or empirical evidence (Aikenhead 2006). Whilst argumentation is an essential aspect of learning science, stories may be particularly valuable for making science more accessible. Drama also invites the observer to enter into the story and experience it more fully (Wong and Pugh 2001). The value of stories is their ability to weave together disparate concepts and tap into familiar experiences and themes, making the science topic more meaningful and comprehensible (Millar and Osborne 1998; Negrete and Lartigue 2004). Graesser et al. (1980) proved that narrative prose generated superior recall compared to expository prose, for a sample of college students. Thorndyke (1977) elaborated how the structure of a plot in a narrative determines the depth of comprehension and subsequent recall. Comprehension is required for encoding of information and formation of schema, the memory structures formed in the brain.

A good story is evocative; it enhances the affective qualities of its subject matter, which can increase enjoyment. The evocative nature of theatre is enhanced through its use of metaphor, where music, characters, movement or objects are used to embody abstracts ideas or concepts (Ødegaard 2003; Winston 2008). The use of imagery produces particularly rich and accessible memories, especially if concepts are presented simultaneously in verbal and visual modes (Clark and Paivio 1991). Mayer (2005) argues that having to integrate information from multiple modalities leads to active learning which most effectively supports long-term retention of knowledge.

Emotional engagement

Artistic activities elicit a variety of emotional responses and theatre is no exception (Ødegaard 2003; Dorion 2009). Emotional arousal renders learning more effective by engaging neural mechanisms involved with memory and attentional focus (McGaugh 2004; Phelps 2006; Immordino-Yang and Damasio 2007; Talmi et al. 2008). Hardiman (2010) noted the value of the performing arts for emotional arousal that enhanced learning.

In the case of science, creating space for emotions as well as cognition may narrow the dissonance between school science and students' cultural identities (Alsop 2001; Immordino-Yang and Damasio 2007). Scientific inquiry is reliant on objectivity to the exclusion of emotional involvement and personal perspectives. This can have the unfortunate consequence of rendering school science alienating for some students.

Positive emotions have important indirect effects on learning. Positive affect is associated with more creative and integrative thinking (Isen, Daubman, and Nowicki 1987). It enhances motivation and interest, both of which are integral to learning and comprehension (Ryan and Deci 2000). Enjoyment of science is strongly associated with interest in science and the desire to pursue it further (Ainley and Ainley 2011).

Design and methods

The effect of the intervention was evaluated with pre- and post-tests of knowledge and attitudes. An experimental design was not possible given the difficulty of recruiting schools for a control intervention, a common problem in educational research (Cohen, Manion, and Morrison 2007). A mixed methods approach, including questionnaires and interviews, was adopted to investigate the variables of interest.

The play

Story of a Seed was a 50-minute, two-actor play about plant reproduction, written by the lead author (a lecturer in plant sciences) and three members of the participatory arts company *Blazing Tales* (www.blazingtales.co.uk). The aim was to create a play that was funny and entertaining, aroused children's interest and appreciation of plants, and increased their knowledge about plant reproduction. The play script and other resources from the play are available online as supplementary materials.

The play is about two plants that encounter each other in a meadow. Arrogant Rosy Wylde (*Rosa canina*) intends to teach the children about botany and affable Gabriel Oat (*Avena sativa*) wants to help her. After a disagreement about which flower species is better than the other, Rosy and Gabriel embark on a journey to learn about how plants reproduce, becoming reconciled to their differences in the process. The characters investigate aspects of floral structure, pollination, fertilisation, seed dispersal and germination, using physical theatre,

Figure 1. (a) Bee pollination scene. (b) Actor miming the shape of the pistil.

stage props (a painted set and plant materials) and music (percussion, recorder and guitar) (Figure 1). The characters consult and interact with the audience as they strive to understand these concepts; a volunteer from the audience assembles the reproductive components of the flower, for example. After each topic, the characters sing a verse and chorus of *The Ballad of the Seed* which captures the key points in rhyming verse. The lyrics are displayed on a flipchart so that the audience may join in. The play also featured three participatory art activities: making a tissue paper flower (following the scene about flower structure), a creative writing exercise about seeds (following seed formation), and a rain-making sound dance (following seed dispersal).

Participants

The study was conducted with five primary schools in Devon (UK), two in an urban, one in a periurban and two in a rural setting. All participants were in Years 5 or 6 (9–10 years and 10–11 years, respectively). A prerequisite for participation was that the students had not yet studied key stage 2 plant reproduction from the UK national curriculum. We invited schools to participate via an email bulletin circulated to all head teachers of schools in Devon. Of the 10 schools that replied wishing to participate, we selected 5 schools. Schools were selected to produce a diverse sample in terms of pupil ability based on literacy and numeracy test scores (Department of Education 2017), socio-economic status based on the Indices of Multiple Deprivation (Ministry of Housing, Communities and Local Government 2015), and location (urban, periurban or rural). We ensured that the sample included schools from the upper and lower quartiles for each parameter. The play was performed in the school hall during lesson time as an enrichment activity towards the end of the school term.

Parents and legal guardians were sent an information sheet prior to the study, asking them to contact the school office if they did not wish their child to participate in the study. Participating teachers circulated (and read out) an information sheet to their students, which included information about how to withdraw from the study. We chose an 'opt-out' rather than 'opt in' system for consent because, in our experience, the return rate of school consent forms is poor, meaning a considerable number of children are prevented from participating in an enriching experience with their peers. Furthermore, the administrative burden associated with consent forms deters some schools from taking part in such studies. This method was approved by the Plymouth University's Faculty of Science Ethics Committee and Schumacher College Ethics Committee.

Pilot studies

An initial pilot performance took place in December, 2014, at a university college, to an audience of 25 adults and children. These led to a number of revisions to the play. First, we realised that some of the jokes in the play were too adult for the target audience and so these were revised. Second, there were scientific inaccuracies in the improvised elements of the play that were corrected, for example, the mechanisms of pollen transfer in insect pollination. This issue was an unavoidable consequence of working with actors that do not have backgrounds in science and highlights the necessity of actor–scientist partnerships in science drama projects. Finally, the participatory activities were refined in terms of verbal instructions given prior to activity, timing and set layout.

A final pilot performance took place in March, 2015, at a rural primary school, to a mixed class of Years 5 and 6 (22 children). The play did not require any further revisions after this second pilot performance. The pre- and post-intervention questionnaires described below for Study1 were used for the first time during this pilot study. No changes were made as the completion rate was deemed satisfactory for all questions

Studies 1 and 2

For Study 1, the play was performed twice in an urban primary school to the Year 5 and Year 6 classes, respectively, and once in a rural primary school to the Year 6 class, in December, 2015 (80 children).

For Study 2, the play was performed twice in a large urban primary school to separate Year 6 classes, and once in a smaller periurban primary school to the Year 6 class, in December, 2015 (64 children). The two studies were identical in all respects save for the format of the knowledge test portion of the questionnaires. In Study 1, the pre- and post-intervention questionnaires contained both multiple-choice and open questions, while in Study 2 they contained only multiple-choice questions. The open questions were omitted in Study 2 because completion rate was low (36.25% for a question about fertilisation and 71.25% for a question about seed dispersal). Study 2 added a final delayed post-intervention questionnaire six weeks after the event.

Questionnaire

Participants completed a questionnaire immediately before and after viewing the play. A subset of 27 participants in Study 2 also completed a questionnaire 6 weeks afterwards to measure the long-term learning outcomes (some of the children who viewed the performance were not available for the delayed post-test). The questionnaire aimed to measure the play's effect on student knowledge achievement and attitudes to plant science, as well as interest and engagement with the play. Pre-, post- and delayed post-questionnaires had identical content for the knowledge and attitudinal sections. The post-questionnaire contained an additional section for feedback about the play. Teachers did not provide test answers or discuss content of the play in class until pre-, post- and delayed questionnaires had been completed.

In Study 1, the questionnaire's content knowledge section required students to label a diagram of a cross section of a flower, complete two four-level multiple-choice questions about pollination and two open questions about fertilisation and seed dispersal, respectively. In Study 2, the questionnaire was revised to consist of eight five-alternative multiple-choice questions following the formats used in a number of previous studies (Peleg and Baram-Tsabari 2011; Kerby et al. (2010); Klepaker, Almendingen, and Tveita (2012).

The attitudinal section of the questionnaires in both studies comprised four statements about plants ('I'd like to learn more about plants in Science, 'learning about plants is difficult', 'learning about plants can be fun', 'plants are one of the most boring subjects in Science'), each with a four-level Likert scale ('*Not at all*', '*A little bit*', '*Pretty much*', '*Very much*'). The attitudinal section was developed from questionnaires on attitudes to school biology in Prokop et al. (2007) and attitudes towards school science in Kerby et al. (2010).

The post-questionnaire of Study 2 also included a section that assessed student interest and engagement with the play based on Kerby et al. (2010). Students were asked to circle words or phrases that most accurately described what they thought of the play ('annoying', 'helped me learn', 'too easy', 'funny', 'too difficult', 'boring', 'interesting', 'didn't learn much'). In addition, two open questions ('what you liked most' and 'what you liked least') invited the student to elaborate on their opinions about the play.

Questionnaires were completed in classrooms under test conditions. Students were not made aware of the schedule of testing ahead of time. Prior to handing out the questionnaire, the researcher stressed that it was not a test and that the questionnaire would not be seen by their teachers. This information was also written explicitly in the introductory paragraph of the questionnaire. Questionnaires were read aloud by classroom assistants to any children with special educational needs. Children were allowed as much time as necessary to complete questionnaires. Completion times did not exceed 20 minutes in any of the trials.

Data analysis – questionnaires

For analysis of the multiple choice questions, each correct answer was assigned a score of one point and each incorrect answer, 'don't know' or uncompleted question was assigned zero points (Cohen, Manion, and Morrison 2007). For analysis of the open content knowledge questions (Study 1 only), each correct fact was awarded one point to a maximum score of six points for the seed dispersal question and six points for the fertilisation question.

The individual question scores were summed to yield a total score for each questionnaire. For each study, paired t-tests were used to assess the following comparisons: pre-test and post-test scores (short-term recall); pre-test and delayed post-test scores (retention); post-test and delayed post-test scores (persistence).

For analysis of the attitudinal section, positive statements ('I'd like to learn more about plants in Science', 'learning about plants can be fun') were assigned a score from 1 to 4, corresponding to the responses 'not at all', 'a little bit', 'pretty much' and 'very much' (Kerby et al. 2010). Negative statements ('learning about plants is difficult', 'plants are one of the most boring subjects in Science') were scored in the reverse direction, from 4 to 1. Therefore, for both positive and negative statements, a higher score indicated a more positive attitude towards plant science. Attitudinal data from Studies 1 and 2 were combined for the analysis and a repeated measures ANCOVA applied, with study number as a covariant. This follows Norman (2010) who argues that parametric tests are found to be robust for Likert data in similar studies.

For analysis of the two open feedback questions, an emerging theme analysis with no *a priori* categories were used (Cohen, Manion, and Morrison 2007; Peleg and Baram-Tsabari 2011). Feedback data from Studies 1, 2 and the final pilot were combined. Cronbach's Alpha was used to measure internal consistency between the four attitudinal questions.

Interviews

In Study 2, 15 interviews were conducted with pairs of children from two of the participating schools, taking place one week after viewing the play. Their purpose was to supplement with richer detail the learning and attitudinal data from the questionnaires. Interviews were audio-recorded. The semi-structured interviews were roughly 10 minutes long and consisted of five leading questions about the play which had been informally tested and reviewed during the pilot phase. Children participated in interviews in pairs selected by the teacher, a format shown by Peleg and Baram-Tsabari (2011) to encourage active contribution and dialogue. The interviewer explained to the children that information in the interview would not be shared with the school and ensured that the interview pace and content was appropriate to age group.

Data analysis – interviews

Audio data from the interviews were transcribed and analysed qualitatively using an emerging theme analysis with *a priori* categories (Cohen, Manion, and Morrison 2007) based on the interview questions. The study authors independently identified emerging sub-categories through immersion in the data. Common subcategories were identified and these were used for the final analysis. Krippendorff's alpha was chosen as a reliability measure for inter-coder agreement as it is satisfies all key criteria for reliability and is specifically designed for content analysis (Hayes and Krippendorff 2007).

Results

Questionnaire – knowledge acquisition

Students were tested on their knowledge of plant reproduction before and after the play (Figure 2). Comparison of the pre and post tests showed a significant gain in knowledge scores in Study 1, $t(80) = 10.479$, $p < 0.001$, as well as Study 2, $t(64) = 10.237$, $p < 0.001$. Pre- and post-test scores were probably higher in Study 2, compared to Study 1, because of the higher completion rate (the two open questions in Study 1 were omitted by 36.25 and 71.25% of students, respectively).

In Study 2, a delayed post-test was given six weeks after the immediate post-test (Figure 3). Comparison of the post- and delayed post-tests showed no significant difference, $t(27) = 0.406$, $p = 0.688$, indicating that the knowledge gain evident in immediate recall persisted over the long term.

Questionnaire – attitudes to plants in school science

Attitudes to plant science were measured before and after the play using a four-level Likert scale ('not at all', 'a little bit', 'pretty much' and 'very much') for two positive and two negative statements about plants in school science. For analysis, responses were scored from 1 to 4, a higher value indicating more positive feeling, and data from Studies 1 and 2 were combined. Attitudinal data had a Cronbach's alpha of 0.70 and 0.71, before and after watching the play, respectively, a satisfactory level of internal agreement between attitudinal statements (DeCoster and Claypool 2004). Attitudinal data could therefore be legitimately collated, to produce a single variable measuring overall attitude to plant science.

Children's overall attitude to plants in school science improved as a consequence of watching the play as shown by a repeated measures ANCOVA, $F(137) = 4.021$, $p = 0.047$, although the improvement was not substantial (Figure 4). The co-variate, study number, showed no significant interaction with attitudinal data, $F(137) = 0.453$, $p = 0.502$, confirming that the differences in knowledge test did not affect attitudinal scores. A comparison of the four attitudinal statements suggests that the most substantial changes in attitude were for the statements 'learning about plants is difficult' and 'learning about plants can be fun' (Figure 5).

Qualitative data

Qualitative perceptions of the play and its affective and educational qualities were gathered through feedback in the post-play questionnaire and semi-structured interviews one week after the performance. The most common themes that emerged in the interviews are shown in Table 1. Data was analysed by the study authors (lead author frequencies are shown where assessor values differed). Krippendorff's ordinal alpha is 0.991 ($n = 21$), a substantial degree of reliability (Hayes and Krippendorff 2007).

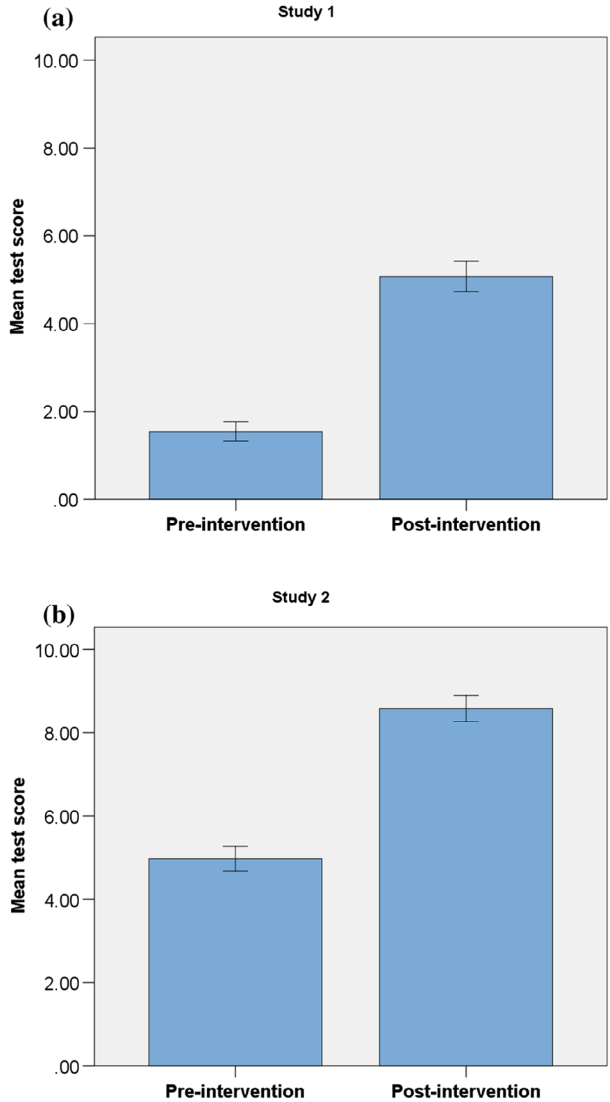

Figure 2. Mean knowledge test scores before and after watching an educational play. (a) Study 1, $n = 80$. (b) Study 2, $n = 64$. Error bars = standard error.

Figure 6 shows the selection rates of descriptive terms that were circled in the questionnaire feedback, and Table 2 lists the types of answers provided to the open questions asking what was most and least liked about the play. These data are discussed in aggregate below.

Perceptions of learning

The majority of students (Figure 6) indicated that the play 'helped me to learn'. Some of the factual information most frequently mentioned in the interviews were the role of bees in pollination and pollen grains in fertilisation. These two topics were particularly memorable aspects of the play. Bee pollination was demonstrated using stage props of a flower cross

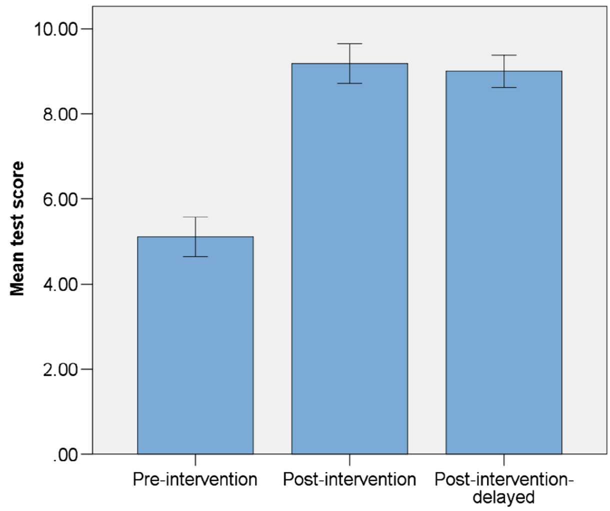

Figure 3. Mean knowledge test scores before, immediately after, and 6 weeks after watching an educational play ($n = 27$). Error bars = standard error.

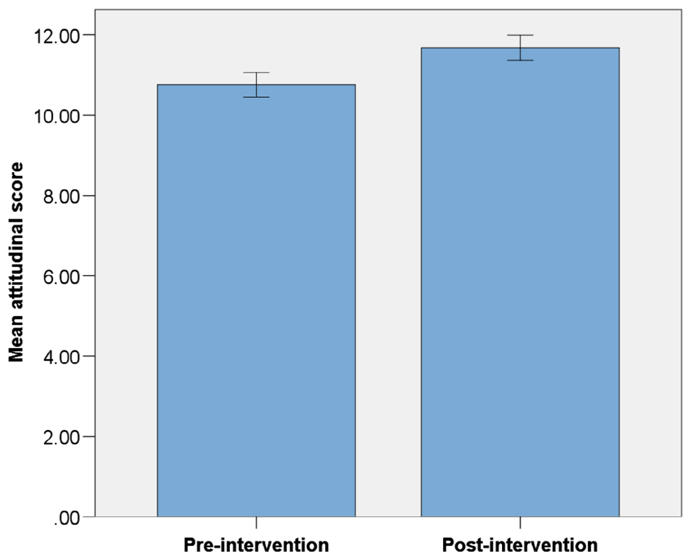

Figure 4. Overall attitude to plant science obtained by combining response scores to four attitudinal statements. Error bars = standard error.

section, a bumblebee and the actors' headdresses. The actors presented germination of the pollen as a piece of prose, with musical accompaniment. The journey of the pollen tubes to the ovary was conveyed in the style of a race commentary, whilst demonstrating the race of the pollen tubes using the stage props:

> Ready steady go: thousands of tubes grow down the style. In the tip of each tube is a male sex cell. Pushing and growing as fast as they can – which one of them will win, who will get the girl? The strongest, the fastest, meets the ovule and, when the male cell inside the tip of the

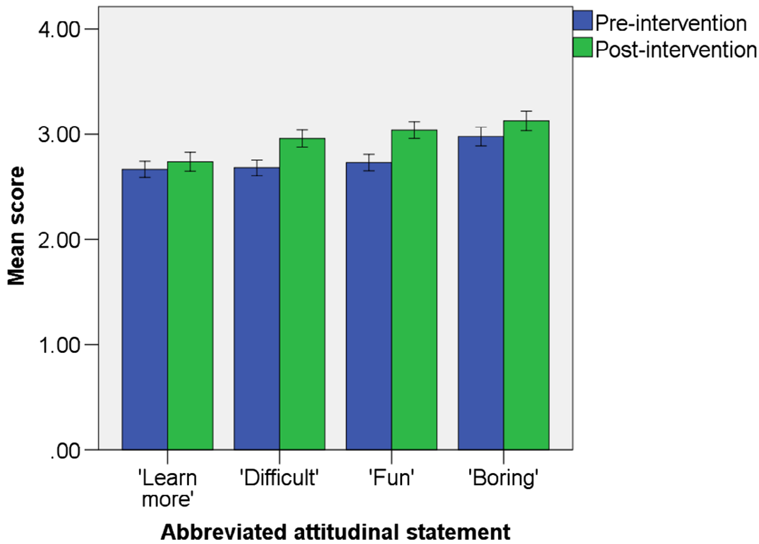

Figure 5. Comparison of mean scores for four attitudinal statements, before and after watching an educational play. Attitudinal statements are 'I'd like to learn more about plants in Science, 'learning about plants is difficult', 'learning about plants can be fun' and 'plants are one of the most boring subjects in Science'. Higher score indicates a more positive attitude.

> pollen tube meet the ovule, they become one. Male and female meet each other and it's like the whole universe explodes as new life is created in that moment of fusion; the moment of fertilization; the birth of the seed.

This student compared how his teacher might have taught fertilisation, compared to the play:

> I think sir would have probably have done, like, with the pollen; but done a line with his pen to say they were racing. But it wouldn't have been the same.

Song and music

An aspect of the play that deserves special mention with regard to learning is the music. In questionnaire feedback, 24% of the children indicated that the thing they liked best was the play's song, *The Ballad of the Seed*. More than half of the interviewees mentioned the song when asked about aspects of the play that helped them learn. For example: 'the songs helped me remember parts of the flower'; 'the song, because it told me a lot'; 'they used songs to give a hint'. The song was considered helpful for learning because it was 'catchy', as this student explained:

> Cause it's got like a tune to it, the tune probably sticks in my mind and I find the words as I go along.

Interviewees found the song helpful for learning because hearing factual information in a rhyming style, accompanied by a melody, assisted recall:

> It's in like a beat so you can hum it and remember. In class we have to jot it down, put it back, get it out later and look at it. But it's like you can feel the beat of it and just remember.

Table 1. Summary of themes identified in interview data, collected through 16 semi-structured interviews with 32 children.

Theme/opinion	Percentage of respondents
Attitudes towards plant science	
Interviewee found plants boring, before seeing the play	46.88
Interviewee felt differently about plants after seeing the play	81.25
Seeing the play has made interviewee feel a greater appreciation for plants	62.50
Seeing the play has made interviewee feel more interested in plants	53.13
Factual learning recalled from the play	
Methods of seed dispersal, for example expulsion, adherence to part of an animal, wind	31.25
The role of the pollen grains in fertilisation	28.13
The role of the bee in pollination	18.75
Perceptions of different elements of the play and influence on learning	
The song had a positive influence on learning	56.25
The song helped learning because it was appealing and memorable ('catchy')	28.13
The song helped learning because singing was a fun or effective way of learning information	28.13
The song was enjoyable, relaxing or uplifting for its musical value	37.50
The flower cut-out helped learning because it was visual, interactive or both	21.88
The flower making activity was enjoyable, rather than educational	37.50
The seed poem was both enjoyable and educational	34.38
The seed poem was thought provoking	25.00
The seed poem was interesting because interviewee found out what other people thought, or had learnt, about seeds	21.88
Opinions about the actors	
One or both actors were humorous	62.50
One or both actors were competent performers ('good')	31.25
Referred to the personality of one or both actors: Rosy as arrogant or spoilt and Gabriel as strict	18.75
Perceptions of the learning environment of the play compared to the classroom	
Interviewee described the classroom environment using one or more of the following terms: completing a worksheet, looking at the board, listening to the teacher, writing notes, working from a book, 'just sitting'	40.63
The play was enjoyable ('fun'), rendering the factual information easier to learn or more memorable than in the classroom environment	34.38
The visual or demonstrative nature of the play made it easier to learn from, compared to the classroom environment	28.13
The classroom environment is boring	18.75
Respondent like the fact that did not have to work or undergo formative assessment during the play	18.75

An example of the rhyming style and factual content is shown in the following verses about fertilisation:

> The sticky little pollen balls / Land on the stigma's end / Pollen finds a perfect fit / And grows a tube to send. / Down the style to the ovary / The pollen tubes then speed / An explosion and a fusion / The creation of a seed.

As well as finding the song helpful for learning, nearly half the interviewees also stated that they enjoyed the singing per se or that they found the music uplifting or relaxing. These two students described the singing thus:

> I was nearly dancing my socks off.

> You had some of the boys singing their heart out.

Songs with subject-relevant content have been used as learning tools for mathematics, biology and chemistry (Pye 2004; McCurdy, Schmiege, and Winter 2008; Crowther 2012;

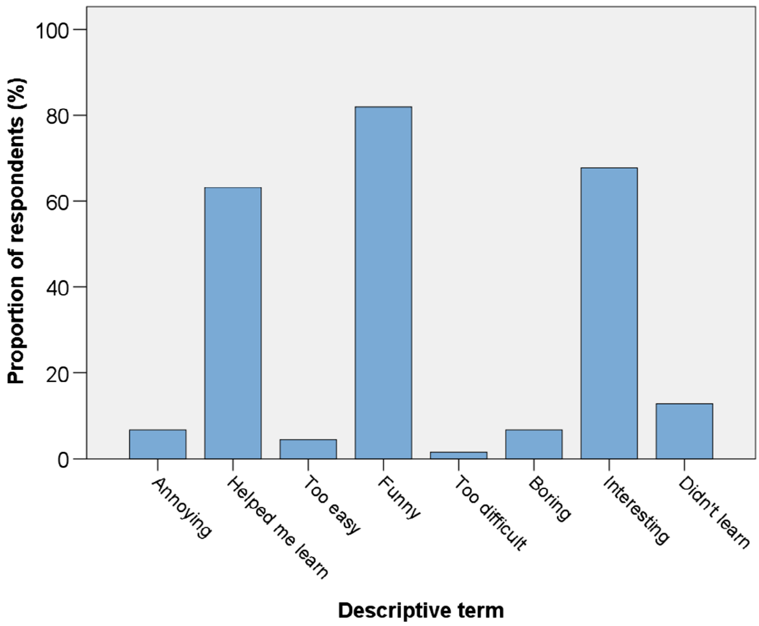

Figure 6. Children's responses to a question that required them to circle words or phrases that described their thoughts of the educational play ($n = 133$).

Table 2. Responses to two open feedback questions. Only responses with 5 or more respondents are shown, 166 children (pilot, Studies 1 and 2, $n = 166$).

What did you like most about the play?	Percentage of children that gave response
Interactive elements	
The song/singing	24.10
Making a flower	19.88
The participatory activities	3.61
The characters or content	
The play or actors were humorous	12.05
Gabriel Oat	5.42
The acting/actors	3.61
The disagreement between the characters at the beginning	5.42
Quality of learning	
The play made learning enjoyable ('fun')	4.82
Learning about plants/flowers	3.61
It was interesting	3.01
What did you like least about the play (or could have been better)	
I liked all of it/nothing needed changing	39.76
The song/singing	5.42
The disagreement between the characters at the beginning	3.01

Lesser 2015). Like Crowther and Pye, we placed song verses at strategic points in the educational intervention as a way of summarising the preceding factual content. Crowther and Davis (2013) postulated that educational songs assist learning in a number of ways. They help to integrate working memory into long-term memory, particularly if the song evokes emotions. The metre and rhyme scheme restricts the choice of words that can be fit to a song, which assists recall. Repetition of verses strengthens information in memory. Finally, song produces rich memories by engaging multiple modalities: auditory music, the kinaesthetic act of singing, the visual nature of reading lyrics and watching actors sing. Crowther (2012) also proposed that the relaxing and welcoming nature of song had a positive effect on learning.

Emotions evoked by the play

Although the emotional content of the drama was complex, positive emotion was most prominent. The play was described as 'funny' by 80% of the children and 12% mentioned humour as their favourite aspect (Table 1). The most common remark made about the actors (63%) was that they were humorous. The play was replete with jokes and innuendo. An excerpt from the opening scene in which the characters criticise their botanical differences, one being a rose and the other a grass plant:

> Gabriel Oat: I may be dull but I'm definitely dependable. Anyway I'm not sure I can trust you; you pop children's balloons.
>
> Rosy Wylde: You're so insignificant; no-one even notices you. I'll end up walking all over you like everybody else does.

Garner (2006) observed that humour incorporated into statistics lectures increased enjoyment and recall compared to a control treatment. Garner proposed that the potential benefits of humour included relaxation and anxiety reduction, the physiological benefits of laughter and creation of a cognitive break between information delivery episodes. Educational science drama projects have often highlighted the important element of humour (Dorion 2009; Kerby et al. 2010; Peleg and Baram-Tsabari 2011). Communication methods that evoked positive emotions in the recipient render the information linked to these emotions more memorable (Negrete 2002).

School science is more accessible if it is compatible with learners' personal identities (Lemke 2001; Warren et al. 2001). Learners tend to be more interested in things that relate to their existing experience and drawing on human interest is a particularly valuable motivational tool in science education (Keller and Burkman 1993). Bowker (2004), for example, found that students' interest in a botanical garden was enhanced by pointing out the relevance of the plants to chewing gum and chocolate. In *Story of a Seed*, Gabriel Oat mimes a kick-off at Wembley Stadium to highlight the importance of grass species to mankind, eliciting enthusiastic responses from the many football fans in the audience.

Learning environment vs. classroom

When asked how they thought the play compared to the classroom, many of the interviewees (41%) described the classroom in terms of a teacher-centred, instructivist environment (Table 1), for example:

> We would have just like looked at the board, seen what information was on it and jotted it down.

Thirty-four per cent of interviewees said that the play was enjoyable, rendering it easier to learn from than class room instruction. The novelty of the play, or the fact that it was not perceived as work, obviously contributed to children's enjoyment, as this example demonstrates:

> But what you did – what your actors did – is a different way. I hadn't experienced it before: so it was a different way, and it was more information, but in a nice, enjoyable way. Rather than: 'get your jotter out, jot things down' and – all that way.

The value of the non-verbal forms of communication for supporting learning, for example, percussion, physical theatre and stage props, was a theme that arose throughout the interviews. The visual and demonstrative qualities of the theatrical medium can help to communicate abstract concepts or ideas in science, which children find difficult to visualise (Winston 2008; Kerby et al. 2010; Peleg and Baram-Tsabari 2011). One student described her experience thus:

> Well, I would have learnt more in the play [than the classroom] because you could see more; but if you said it in words then it would be a bit confusing. But because I've seen, like, the sculptures, the art and how they move it, how they travel, how the plants (and inside of it) and the pollen and the bees, yeah, but in a lesson we would just obviously just find out, like, how it would move. We wouldn't actually see it for ourselves.

Another student compared the stage prop of a flower cross section to the whiteboard in the classroom:

> I thought they [the stage props] were very interesting because, instead of drawing a big diagram, you've got a model of a flower and you're actually moving it around; makes it even more interesting.

Participatory art activities

The play included three interludes during which children took part in art activities on the theme of plant reproduction. The first involved crafting a tissue paper flower. The second was a creative writing exercise where the groups composed a sentence starting with the words: 'a seed is …' The actors read these sentences in random order in the style of a poem. The third was a rain-making sound dance. The flower creation was particularly popular with 20% of students citing it as their favourite aspect of the play (Table 2). Many students felt that the flower crafting (22%) and poem writing (34%) benefited learning. 22% students described the exchange of ideas with peers in the latter activity as thought-provoking, for example:

> It was really interesting and funny about what other people thought about plants, and what they now think about seeds after learning about them a bit more.

These departures from the main activity of the performance might be beneficial in several respects. Rinne et al. (2011) described how creating a work of art on a particular topic requires students to create a background context for learning, which enhances memorisation, an effect they describe as elaboration. The art activities provided an opportunity to recall and reflect upon things learned earlier, an effective technique for long-term retention (Roediger and Pyc 2012). Even if the activities contribute more to enjoyment than learning, breaking up a lesson at strategic points can help to sustain student attention (e.g. Prince 2004).

Attitudes towards plants

Children's overall attitude to plants in school science, as measured by a Likert scale, significantly improved as a consequence of watching the play, although the increase was not substantial (Figure 4). Most of the children interviewed (81%) claimed to feel differently about plants following the play. Many said that they had previously found plants boring (47%), describing plants in passive terms: 'they are just there' or 'they don't really do much'. Plants were now perceived as adaptable, intelligent and intriguing, as these two examples demonstrated:

> Before the play I thought plants were quite dull and boring, after play it kind of gave a whole different side of the plants.

> You don't really know what is going to happen about them like how they are what they do and stuff. You can't really say: 'oh, that was going to do that; you have to wait and see.'

Some children felt that learning more about plants increased their interest in them:

> Now I know more about plants I think they're more interesting. I learnt a lot from the play and that's what got me into it.

This is a notable outcome given the frequency with which the declining interest in plants is highlighted in the biological education literature (e.g. Drea 2011; Levesley et al. 2014). Other interventions that have been shown to have a positive effect on attitudes towards plants are visits to botanic gardens and experiential outdoor programmes (Bowker 2004; Lindemann-Matthies 2006; Sanders 2007; Fančovičová and Prokop 2010).

Conclusions

Story of a Seed demonstrates the potential that an interactive theatre production offers for enhancing appreciation and interest in plants and plant science. Questionnaire and interview data both indicated an increase in positive attitudes towards plants among the students. Given concerns about declining interest in science in the post-primary school years, this form of early intervention has value by itself. However, the experience was shown to have lasting educational value as well. Learning about plant reproduction was evident in tests of immediate recall, and this knowledge showed long term retention when tested six weeks later.

As anticipated from the theoretical stance of the study, emotional engagement played a key role in supporting children's learning and interest development from the play. The main emotional responses to the play were enjoyment and humour, which can be attributed to the musical content, the comic behaviour of the actors and the participatory activities, as well as the general experience of the theatrical performance. In contrast, there was little evidence that the play's narrative contributed to learning or interest, The plot structure was not particularly complex in *Story of a Seed* so this may explain why narrative did not form an important part of the educational experience. However, the use of metaphor in the play was found to support learning. Non-verbal forms of communication, namely music, physical theatre and stage props, assisted children's understanding of biological concepts and processes in the play, for example, pollen grain movement and floral structure. These findings highlight the value of integrating arts-based activities into science education, for producing positive affect and supporting conceptual learning. Arts-based activities could be used as cognitive breaks between episodes of information delivery, for example, in the form of a thematic song or a participatory art activity, like those created for *Story of a Seed*.

An appealing feature of educational theatre and other dramatic activities is their accessibility, relatively low cost and that thhe activity can take place on the school premises. Although our production of *Story of a Seed* used professional actors, the expense was moderate when one considers the numbers of students engaged with multiple performances at different sites. Out-of-class educational experiences like these are most effective when delivered in conjunction with class-based learning before and after the experience (Bowker 2004; Peleg and Baram-Tsabari 2011). Moreover, the materials of *Story of a Seed* could be utilised independently by schools. For example, the script and *Ballad of the Seed* song could be used as the basis of a student production. In conclusion, we propose that this study provides compelling evidence for the benefits that art-based activities in science can provide alongside inquiry-based ones.

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Meeting Linnaeus: improving comprehension of biological classification and attitudes to plants using drama in primary science education

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ABSTRACT

Background: Children's interest in science is known to decline around the upper primary age, and botanical topics are unpopular with students. Drama in education has the potential to increase motivation and interest in school science.

Purpose: The study examined the impact of immersive drama on knowledge about biological classification and attitudes towards plants. The drama workshop, informed by the life of eighteenth century biologist Linnaeus, included inquiry-based learning with living plants.

Sample: Four primary schools in Devon, UK were recruited for the study and a total of 108 students (aged 10–11 years) took part.

Design and Methods: A mixed methods approach was adopted. Quantitative analysis of pre- and post-intervention knowledge and attitudinal assessment was combined with qualitative analysis of semi-structured interviews which made use of emerging theme analysis with *a priori* categories.

Results: Pre- and post-intervention tests indicated increases in knowledge as well as positive attitudes towards plants. Questionnaires and interviews identified elements that were particularly beneficial for learning and enjoyment, namely the sensorial experiences with plants, physical drama games, authentic problem-solving activities and the overall participatory nature of the workshop.

Conclusions: The drama workshop produced measurable positive gains in learning and attitudes in school science. The participatory aspects of the drama and the experiences with live plants, contributed to the successful outcomes of the study.

KEYWORDS
Drama; arts; attitudes; primary science; plants

Introduction

Children enjoy science at primary school level but their interest in science begins to decline at the age of 10 years (Archer et al. 2010; DeWitt et al. 2011). Learners of all ages exhibit a particularly low interest in biology topics relating to plants, a phenomenon described as 'plant blindness' (Wandersee and Schussler 2001; Schussler and Olzak 2008). Theatre in education is known to increase engagement in school science, notably

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for less popular topics (Saricayir 2010; Cakici and Bayir 2012; Abed 2016; Stagg and Verde 2018). Drama encouraged interest in such topics by generating emotional pleasure and through its emphasis on social collaboration. Creating visual and meaningful representations of scientific phenomena through role playing and physical drama assisted the understanding of abstract concepts.

Theatre in education was inspired by John Dewey's pedagogic theory, aiming to transform learning into a deep, educative experience via the aesthetic and affective qualities of theatre (Abed 2016). Such qualities are particularly valuable in science education. Negative attitudes and low interest towards science have been linked to the disparity between everyday life and the seemingly emotion-free, objective world of science (Osborne, Simon, and Collins 2003). The value of integrating arts and creative activity into science education has been brought to the foreground by the 'STEM to STEAM' movement (Sousa and Pilecki 2013). Theatre in education ranges from productions with little audience participation to interactive drama and roleplaying where the audience are co-creators of the performance (Ødegaard 2003). Theatre in education can improve attitudes and motivation in science education while also fostering learning (Kerby et al. 2010; Abed 2016; Toonders, Verhoeff, and Zwart 2016).

This study investigates the impact of a drama workshop about the biologist Carl Linnaeus and plant classification on upper primary school children's learning and attitudes towards plants. The classification of living organisms is a key topic in school biology curricula but is one that students and trainee teachers alike find difficult (Yangin, Sidekli, and Gokbulut 2014). Linnaeus, the originator of the modern biological classification system, had an eventful botanical career that lends itself well to storytelling. McGregor (2014) demonstrated that dramas based on the life and work of famous scientists are effective for increasing enjoyment, motivation and higher order learning in primary science.

The workshop was based principally on process drama, a genre where the group is immersed in a scenario and 'lives through' the imagined experience (Bowell and Heap 2013). The year is 1735 and Linnaeus has come to the school to recruit 'apostles,' students to be sent on overseas specimen-hunting expeditions (Müller-Wille and Charmantier 2012). Linnaeus subjects the class to a series of challenges to assess their suitability. Process drama is representational rather than presentational, meaning that group members are held within the created dramatic context for the duration of the workshop as active players (Neelands and Goode 2015). Process drama often features a 'teacher-in-role' (in this instance an actor-educator playing Linnaeus), a context-relevant character who guides the dynamics of the drama and supports the other group members in developing their roles (Bowell and Heap 2013). Although process drama is at times described as an unscripted, improvised genre (O'Neill 1985), the workshop featured both improvised and scripted elements. This is a known method for portraying historic characters in educational drama (Ødegaard 2003; Jackson and Leahy 2005). The scripted elements help to create a vivid tableau of the personality and their endeavours, whilst improvisation opens up the way for an active dialogue and shared inquiry with the participating group.

The workshop shared characteristics with Heathcote and Herbert (1985) 'Mantle of the Expert,' a genre in which group members are positioned as experts in a specific branch of knowledge who must apply their expertise to a specific problem. The drama organiser plays a subordinate role, whose main function is to inform the group of what is required from them. An example would be a messenger seeking help from the experts, who also signposts them to the information they need to develop their roles. In common with this genre, the workshop was based on the social construction of knowledge but participants (playing the roles of eighteenth century botany students) could only be described as partial experts. In contrast to this genre, the workshop's Linnaeus was the intellectual superior and central communicant in the group and remained in role throughout.

The project aim was to investigate the effect of participation in the drama workshop on Primary Year 6 students' knowledge of biological classification and attitudes towards plants. The research questions were as follows:

(1) Was there a significant change in children's attitudes toward plants before and after the drama workshop?
(2) Was there a significant gain in children's knowledge about plant classification before and after the drama workshop?
(3) What were the children's qualitative perceptions of the drama workshop and how did specific elements influence learning and attitudes?

Theoretical framework

The drama activities and sensorial experience of plants in the study's workshop can be examined in the context of embodied cognition theory which proposes that cognition is grounded in the body (through sensory-motor processes and interactions with the environment) as well as the brain (Varela, Thompson, and Rosch 1991). Adding meaningful sensory-motor experiences to educational interventions improves retention and recall (for a review, see Kiefer and Trumpp 2012).

The idea that drama and role playing could benefit learning based on embodied cognition theory was first proposed by Scott, Harris, and Rothe (2001). They found that improvising and acting out scenes referred to in a passage of text led to superior recall of the text content compared to control treatments (reading text, writing about the text, discussing the text). Scott Harris and Rothe argued that the encoding and retrieval of information was enhanced by actively experiencing it. The value of role playing for involving children both physically and intellectually in science learning has been noted by others (McSharry and Jones 2000). Drama is a form of co-operative play which Piaget regarded as an essential part of children's cognitive development. Role playing produces vivid analogies which support children's understanding of scientific concepts and the creation of robust mental models (Aubusson and Fogwill 2006).

As well as engaging children in a role playing drama, the workshop sought to provide children with multi-sensorial experience of live plants. A variety of plants were passed around during the workshop which children were encouraged to smell, feel and closely inspect. Species with distinctive appearances, textures, smells or size were used to heighten the sensorial experience. Auer (2008) found that sensory perception, which he described as 'cognition through the physical senses,' encouraged deeper learning about plants in a group of undergraduate students. Auer proposed that employing all the external senses assists plant identification by promoting associative memory, enabling a physical stimulus (e.g., smell) to cue information retrieval (e.g., species name). Engaging the motor system by holding and manipulating plants is also expected to contribute to learning based on embodied cognition. Glenberg et al. (2004) showed that manipulating three-dimensional objects improved learning in children compared to experiences with no manipulation. They argued that manipulation improves learning through the generation of complex mental models. Finally, the use of drama in education has often been motivated by its entertainment value, and enjoyment is known to have important indirect effects on learning. It is associated with more creative and integrative thinking (Isen, Daubman, and Nowicki 1987). It enhances motivation and interest, both of which are integral to learning and comprehension (Hidi 1990; Keller and Burkman 1993).

A drama workshop that incorporates role-playing and interactions with live plants offers physical and sensorial experiences that are known to promote learning. Combined with engaging and enjoyable activities and storytelling, the workshop is expected to produce measurable positive changes in knowledge and attitudes toward science.

Design and methods

The effect of the drama intervention was evaluated using pre- and post-intervention tests of knowledge and attitudes. A mixed methods approach, with questionnaires and interviews, was employed to investigate the variables of interest in depth.

Participants

Schools were recruited by circulating an announcement about the project to head teachers and science curriculum leads. A prerequisite for participation was that the students had not yet studied key stage 2 biological classification from the UK national curriculum. The workshop offered a free enrichment activity relevant to the curriculum which required minimal input from teachers.

Five Year 6 classes (10–11 years) participated in drama workshops from 25 September to 6 October 2017. The five classes were from four state-funded schools (one school had two Year 6 classes), three of which were in an urban location, and one rural. Workshops took place in school halls during the regular school day, with one class participating per workshop (between 20 and 27 children). A total of 108 children took part. Procedure and personnel were identical for all classes.

Pilot work to develop the drama, activities, and test materials was conducted in two additional schools in Manchester and Devon (UK) prior to the study.

The drama workshop

The 90 minute workshop was produced by the director of a theatre-in-education company and the author. The workshop was facilitated by a professional actor from the theatre-in-education company as 'Linnaeus.' The researcher participated in a minor role as an 'apostle' who had accompanied Linnaeus to England to provide assistance. The apostle distributed and collected workshop resources and supported Linnaeus in scaffolding children's learning during the games and activities. The stage set consisted of Linnaeus's travel trunk, mobile herbarium and a table of books and plant specimens. There was no distinct performance space; the class was seated around the table or trunk, in a circle or small groups depending on the scene or activity.

In the scenario, the children took the roles of eighteenth century botany students eager to see the world. Linnaeus, hoping to recruit apostles for his plant-hunting expeditions, guided them through a series of challenges to assess their suitability. The activities were interspersed with partially scripted, dialogic scenes about his life story, his interest in botany and the new classification system he was developing. The narrative was illustrated with plant specimens circulated around the group (Figure 1(a); Supplemental File 1).

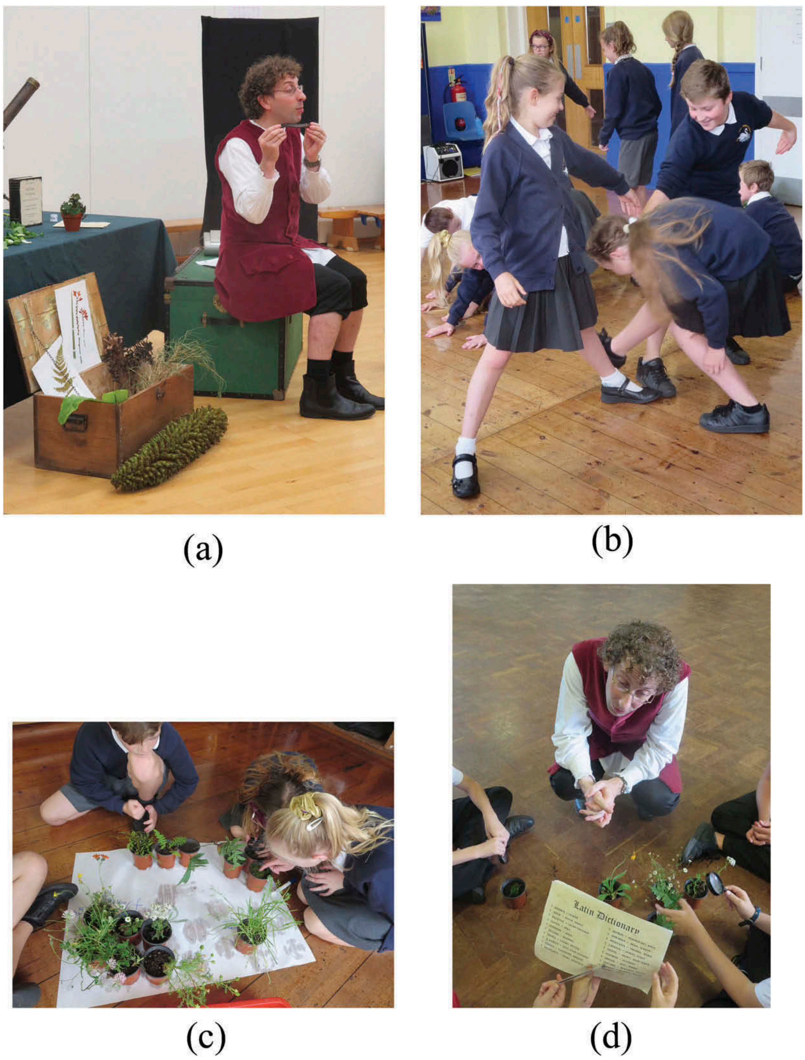

Figure 1. (a) Linnaeus presenting plant specimens. (b) Children playing the 'explorer' game. (c) Classification activity using potted wild plants. (d) Binomial plant naming activity.

The challenges comprised three drama games and two small-group activities (Supplemental File 2). The 'ambition' game, in which Linnaeus related his experiences as a biologist and encouraged the prospective apostles to mime their own career aspirations, served as a warm-up exercise that established trust and confidence. The remaining activities focused on themes of botany and classification. In the 'explorer' game, the class role-played an expedition to find a rare plant (Figure 1(b)). In the 'classification' game, pupils co-operated to arrange themselves into groups according to characteristics such as the first letter of their name, eye and hair colour and favourite interests. In the small group activities, pupils were given trays of thirteen potted wild plants to classify according to observed similarities and differences (Figure 1(c)). Children then created scientific names for plant specimens using a key to identify the species' genus and a Latin dictionary to choose an appropriate descriptive word for the second part of the binomial name (Figure 1(d)).

Ethical procedures

Two weeks prior to the workshop, schools distributed an information sheet to parents and legal guardians with the details and motivations of the study, including an opt-out slip for those who did not wish to participate. Class teachers also read and circulated a similar information sheet to pupils which included information on how to withdraw from the study, at any point they wished to. Anonymity was assured at all times. An opt-out design was chosen as it reduces the administrative burden for schools and parents. ent form for photographing or video recording used an opt-in system (only children with parental permission were photographed or filmed). All methods used in the study had been approved by the Plymouth University Ethics Committee.

Questionnaire

Participants completed a questionnaire immediately before and after participating in the workshop. The questionnaire was incorporated into the narrative of the drama, wherein the apostle approached the children to help with a scientific experiment prior to Linnaeus's arrival. The questionnaire was designed to measure the workshop's impact on student knowledge and attitudes to plants (Research Questions 1 and 2) and on their interest and engagement (Research Question 3). A subset of 23 participants completed a questionnaire two months afterwards to measure the long-term learning outcomes. Pre-, post- and delayed post-intervention questionnaires had identical content.

The attitudinal section was based on the Plant Attitude Questionnaire designed by Fančovičová and Prokop (2010) to measure attitudes to plants in children aged 10–-15 years. The assessment tool comprised 15 response items using a five-point Likert rating scale. Response items were designed to measure three attitude dimensions: interest (6 items), importance (4 items) and enjoyment of plants (5 items) (Table 1). The Likert rating scale was illustrated with animated emoticons ranging from very happy (strongly agree) to neutral (strongly disagree) (Figure 2), following Hall, Hume, and Tazzyman (2016), who found it to be a highly effective method for eliciting the full range of Likert scale responses in 9–11 year-olds.

The knowledge section comprised 8 four-level multiple choice questions that assessed learning and understanding of the workshop topics. Each question consisted

Table 1. Statements used in the attitudinal response items of the study questionnaire. Response items are grouped according to attitude dimensions ('Interest', 'Enjoyment' and 'Importance').

Attitudinal statement
Interest
I like learning to identify wild flowers
Plants all look the same
Plants are dull
I feel amazed by how many plant species there are in the world
I'm not interested in looking at the plants I see outdoors
Plants do interesting things
Enjoyment
It is relaxing to be around plants
I don't like studying plants in class
Learning about plants is fun
I enjoy looking at plants in class
Learning about plants is stressful
Importance
Humans cannot survive without plants
All life depends on plants
I don't need to learn about plants
We should study plants as much as animals

Figure 2. Example response item. Likert scale reproduced from Hall, Hume, and Tazzyman (2016).

of four possible answers (including a 'don't know' option) and instructions to tick one box. The length and design of the knowledge test was similar to that used successfully by Peleg and Baram-Tsabari (2011). The post- questionnaire also included a feedback section, comprising 2 closed questions ('yes' and 'no' options to 'did you enjoy the workshop' and 'did the workshop help you learn') and 2 open questions ('what did you like most' and 'what did you like least') following Stagg and Verde (2018).

The pre- questionnaires were administered at the beginning of the workshop in the school hall prior to Linnaeus's entry. Linnaeus's apostle (the researcher) explained to the children that she and Linnaeus was interested to find out what they knew about plants as part of their science investigations. The researcher asked children if they were happy to complete a questionnaire, without conferring with each other, as that would affect the results of their investigations. The researcher stressed that it was not a test and that the questionnaire would not be seen by teachers. The questionnaire was read aloud by the researcher and children were allowed as much time as necessary to complete it (10 minutes on average). The post- questionnaire was administered under the same conditions following Linnaeus's departure.

Interviews

The purpose of interviews was to supplement with richer detail the learning and attitudinal data from the questionnaires, specifically in relation to Research Question 3. The semi-structured focus group interviews consisted of a series of leading questions about the workshop to identify children's perceptions of the drama workshop, and to investigate how different elements of the workshop influenced cognitive and affective learning.

Interviews were conducted one week after the workshop in all four schools. Pupils were interviewed in groups of three, a number that encourages active contribution and dialogue (Bowker 2004; Peleg and Baram-Tsabari 2011). The teacher was requested to select 6–8 mixed ability triads that were as representative of the class as possible. The audio-recorded interviews took place during the school day in a location adjacent to the classroom. All interviews were conducted by the researcher and the children were told that interview content would not be shared with the school. Interviews were approximately ten minutes in length. In total, 72 children were interviewed.

Results

Questionnaire – attitudes to plants

Two questionnaires had to be rejected due to partial completion, giving a sample size of $n = 106$. For the attitudinal section, each statement was assigned a score from 1 to 5 (a higher score denoted a more positive attitude toward plants). Cronbach's Alpha provided an index of internal consistency for scores within each dimension, yielding values of 0.81 for interest, 0.74 for enjoyment and 0.51 for importance in the pre- test and 0.87, 0.85 and 0.67 respectively in the post- test. The results indicate that consistency was high for the interest and enjoyment questions but only fair for the importance questions, particularly in the pre- test.

A mean score was obtained from the items in each attitude dimension (interest, enjoyment and importance) (Table 2). Wilcoxon signed ranks tests were used to compare the pre- and post- test scores for each of the dimensions. Significant positive changes in attitude were observed for interest, $Z = 3.198$, $p = .001$, enjoyment, $Z = 3.398$, $p = .001$, and importance, $Z = 2.399$, $p = .016$.

Table 2. Mean attitudinal scores for three attitudinal dimensions based on a five-point Likert scale, before and after participating in a drama workshop ($n = 106$). Standard deviations shown in brackets. Higher values indicate a more positive attitude.

Dimension	Pre-Intervention	Post-Intervention
Importance	3.60 (0.84)	3.81 (0.95)
Enjoyment	3.31 (0.94)	3.55 (1.09)
Interest	3.71 (0.95)	3.86 (1.07)

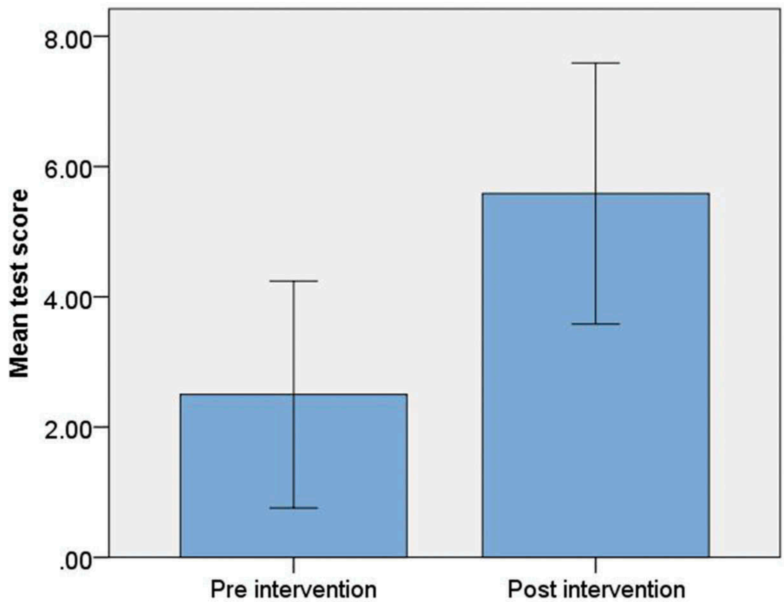

Figure 3. Mean knowledge test scores, before and after participating in a drama workshop. Error bars = standard deviation.

Questionnaire – knowledge acquisition

Comparison of the pre- and post- knowledge tests showed that children's knowledge increased as a result of participating in the workshop (Figure 3). A Wilcoxon signed ranks test indicated that this change was significant, $Z = 8.668$, $p < .001$.

A subset of children ($n = 23$) completed a delayed post- test two months after the immediate post- test (Figure 4). The difference between immediate and delayed post-tests was significant, $Z = 2.274$, $p = .023$, indicating some loss of knowledge. However, the delayed post- test score was still significantly higher than the pre- test, $Z = 3.846$, $p < .001$, indicating substantial knowledge retention.

Qualitative feedback on the workshop

The two open questions from the feedback section of the post- tests were analysed using an emerging theme analysis with no *a priori* categories (Cohen, Manion, and Morrison 2007; Peleg and Baram-Tsabari 2011).

Audio data from the interviews were transcribed and analysed qualitatively by the author using an emerging theme analysis with *a priori* categories (Cohen, Manion, and Morrison 2007). An initial set of categories was based on interview questions with additional categories developed through immersion in the data. Each participant's statements were then subjectively coded by the researcher into these categories. As validation of this coding, an independent coder applied the same coding to a sample of data (50% of the statements) and inter-coder agreement was assessed using

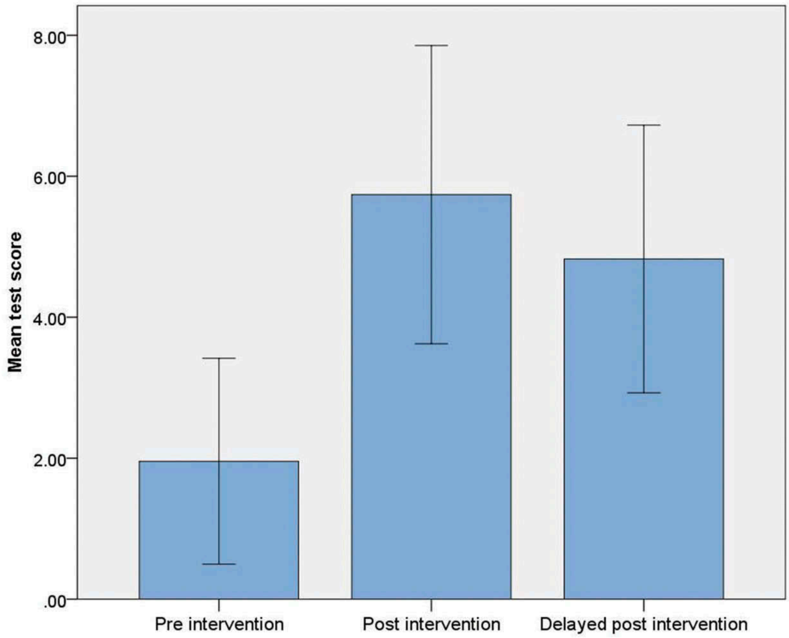

Figure 4. Mean knowledge test scores, before and after participating in a drama workshop (immediate and delayed) (n = 23). Error bars = standard deviation.

Krippendorff's Alpha (Hayes and Krippendorff 2007; De Swert 2012). Krippendorff's alpha was 0.93, indicating a high level of agreement between the two coders.

Enjoyment and learning

In post-intervention questionnaires, 94% of children responded 'yes' to the question 'did you enjoy the workshop' and 92% to the question 'did the workshop help you learn.' In interviews, 92% said that they found the workshop enjoyable or helpful for learning. Many children described the workshop as 'learning in a fun way' or said enjoyment helped learning:

> Because it was more fun I remembered – I could remember all what we learnt

> I think the more fun it is, the more you learn

The fact that nearly all participants perceived the drama workshop as enjoyable and educational is a strong indicator of success. Positive affect is known to increase learners' intrinsic motivation and ability to work effectively at a task (Isen and Reeve 2005). Experiences that evoke positive emotions in the participant render information more memorable (Negrete 2002). Enjoyment increases student interest in science and the desire to pursue it further (Ainley and Ainley 2011). The workshop is an example of situational interest, defined as positive affect specific to an immediate situation, which is known to foster individual interest, a sustained commitment to the subject domain.

When asked how the workshop compared to their usual science lessons, the majority (74%) stated a preference for the workshop or said that they enjoyed it more than usual science. Virtually all respondents provided a specific reason for their answer, indicating that the workshop's popularity was not due purely to novelty value. Approximately a third of respondents said it was primarily because the workshop was more participatory or 'hands-on' than usual science; a third because they liked drama; and a third because they encountered real plants, which they didn't normally in science class.

> Usually we'd be writing down stuff but we actually got to do stuff

> We got more involved instead of just writing in books

> I enjoyed it more partly because I like drama; I like acting and drama

> In our science lessons we never really got to look at plants that closely and allowing us to that, that was really fun

The majority (86%) of the 59 children that described their usual science lessons used the words 'writing', 'sitting', 'PowerPoint' or 'whiteboard', for example:

> Being showed a PowerPoint about it

> Sit and listen then write stuff

> You learn about things on the board and make notes

Several children also bemoaned the fact that they usually had pictures, models or discussion about plants instead of studying live ones:

> We just talk about the plants, we don't look at them

A similar observation was made by Jackson and Leahy (2005), who found that children enjoyed museum drama events as they were more 'hands-on' than usual classroom activities of listening, looking or taking notes. Whilst UK science education strives to be learner-centred, didactic modes are unavoidable given the constraints imposed by curricula, class sizes and teachers workloads. Novel out-of-classroom interventions are known to be an invaluable addition to science education, notably for increasing motivation or providing original experiences (Braund and Reiss 2006; DeWitt and Storksdieck 2008).

Attitudes to plants

When asked if the workshop had changed what they thought about plants, 70% of interviewees said 'yes.' The majority of these attributed a change in attitudes to encountering novel or interesting plants, or learning about plant diversity. Some people added that plants had seemed boring before the workshop, because they always saw the same ones:

> Here were different plants that I hadn't seen before; I was bored of plants at my old school, all the plants just looked the same

> When you think of plants you mainly just think of the normal ones, like daisies and dandelions… if they went to that workshop they would be able to say more advanced ones

> Now I am thinking they are exciting because there are loads of different species

Table 3. Responses to two open questions about the workshop. Only responses with 10 or more respondents are shown (n = 106).

What did you like the most about the workshop?	Percentage of children that gave response
Encountering novel or interesting plants	37
The plant activities (classification or naming)	17
The drama games or taking part in drama	27
It was educational	13
What did you like the least about the workshop?	
Nothing/I liked it all	50
The plant or drama activities	13

This finding was consistent with questionnaire data in which the most common response to the question about favourite aspect of the workshop was 'encountering novel or interesting plants' (Table 3). Other children attributed changes in attitudes to simply finding out more about plants or, more specifically, the importance of plants for human survival:

> I didn't really know what they were for. So I was just like: "plants, oh, useless, basically." But now, I'm like: "I know what plants are for"

> They told us more about them, and how they live and everything, and it really interested me

> They are not just there for the sake of it, they are actually quite useful

The remainder expressed an increased appreciation of plant complexity or plant science as a reason for their change in attitude:

> Like the pineapple – it's not related to a pine or an apple. That really interested me because then you could understand how much work goes into naming the plant and finding the species

> Before that I thought there's no point in being interested in plants because they were all discovered

Overall, 74% of children responded that they enjoyed or liked the plant activities in interviews and, in questionnaire feedback, more than half mentioned plants in their favourite aspect of the workshop (Table 3). Other studies studying the impacts of learning on attitudes towards plants have concluded that first-hand, positive encounters with plants are essential for attitudinal change (Lohr and Pearson-Mims 2005; Fančovičová and Prokop 2011; Çil 2016).

Physical and sensory experience

We investigated whether the physical drama activities or sensorial experience of plants contributed to learning from the workshop as might be predicted by embodied cognition theory. 74% of interviewees expressed positive opinions about drama in the workshop and 40% of interviewees mentioned the physical nature of the workshop as important for learning or enjoyment, using the terms 'active', 'physical', 'moving around', 'practical' and 'getting up'. Participants described the physical qualities of drama games in great depth, for example crawling through the human obstacles in the 'explorer game', whether they were 'caught' by carnivorous plants or reached the 'rare plant.' One third of participants described the physical aspects or drama as directly beneficial to learning, mainly in terms of benefits for information retention:

> You got to move around playing games; it got it into your head

> You act it, and it helps you remember stuff

> I think it almost stuck in my head more because I love drama and acting

Embodied experience of plants in the workshop included multiple sensory modes (visual, olfactory and tactile), as well as manipulation, for example holding up and moving plant specimens, writing plant labels to insert in pots, and viewing of morphological features through a magnifying glass. 68 % of children mentioned embodied experiences in interviews. Half of these were olfactory or tactile experiences:

> You got to touch them, know what they're like; you can smell them

> I don't think many people knew about the one where you rub it and it smells of pineapple

> Basically, they all have a different touch. I learnt the different feel of them – one had weird hairs on it – every single plant felt a bit different

Many children mentioned the observation of plants using magnifying glasses as an important experience:

> The one that had the hairs on – I didn't realise that 'til I got the magnifying glass

> I wouldn't look at a plant here now and say: "oh, that's got spots on". You had to be really close – and the magnifying class helped with that

Others mentioned that in-depth observation of plants had contributed to learning or increased their awareness of plants in the local environment:

> I'd never looked at moss long enough to know it has spore capsules

> I had never noticed that those ferny things had the spores on the back

> I've been seeing them in my garden and where I walk past; I like the "granny pop out of bed" one

It should be noted, however, that some of the perceived learning benefits of the activities came not from the physicality *per se* but from the feelings of empathy or appreciation they engendered in the participants:

> You got to actually be there and be one of those explorers

> When we were doing the obstacle course… you learnt how back then that actually did happen to a lot of them

> It showed what you want to become when you're older, the obstacles you have to overcome

Physical activity was also seen as providing valuable interludes of exercise or entertainment between learning:

> Since it wasn't all just sitting down – probably helped you concentrate more

> Sitting in there [motions at classroom] your legs can get quite stiff – and there you got to move around

> Because we actually got to move around and shake ourselves up and stretch; it was really fun

The benefits of physical activity for children's cognitive functions are well documented (e.g., Sibley and Etnier 2003). Best (2010) discussed how mentally demanding exercise, namely activities requiring high co-ordination of motor movements or problem-solving, is most likely to benefit cognitive functions. This argues for the role of drama as a physical activity that supports learning. Garner (2006) described how incorporating humour into a mathematics lecture improved recall, which he surmised was because the humour provided cognitive breaks between information delivery episodes, with associated benefits of relaxation and anxiety reduction. The same principle could be applied to the use of physical or drama games as interludes between instructional episodes.

The recurring theme in interview feedback about the plant experiences was that children felt enhanced interest or appreciation of plants as complex and diverse organisms. Previous studies have identified that sensorial experience of plants increased appreciation of plants (Nyberg and Sanders 2014) and environmental awareness (Auer 2008; Beery and Jørgensen 2018). Based on Glenberg et al.'s (2004) study proving that manipulating three-dimensional objects improved learning in children, we might expect this tactile experience of plants to deepen the mental models formed during learning, compared to observation of plants alone.

Authentic learning

40% of interviewees said that the dramatic scenario (meeting Linnaeus and helping him with his work) helped them to learn, with many adding that it made concepts easier to visualise or to understand. 39% of interviewees said that the scenario felt genuine, usually with the terms 'it felt real' or 'felt like someone in real life':

> I thought was that actually him – a scientist

> When we got more into it I felt like I was in it – the time, Linnaeus's time

> You can imagine what it would be like to be Carl Linnaeus

36% of interviewees said that the plant classification and naming activities made them feel like real scientists, or applauded the authentic problem solving:

> You felt like an actual scientist, naming your own plants

> It's like how the professionals do

> We got to make our own categories…in class we'd have been told what categories to put them in

> We were allowed to think what we thought, not what the marking system thought

Children were not treated as school pupils but addressed as 'future' or 'fellow' scientists in the workshop. In their own work, Jackson and Leahy (2005) noted how liberating children found this aspect of their drama experience. Warner and Andersen (2004) surmised that being assigned an adult scientist role increases the sense of responsibility children take in their own inquiries.

Like any genuine scientific inquiry, activities did not have prescribed outcomes and, since real plants were used, a variety of classification systems or names could be created. This agrees with Herrington and Oliver (2000) recommendations for teacher support and learning structures which emphasise the importance of a complex open-ended learning environment and collaborative learning. In interviews, 49% mentioned the participatory or 'hands-on' nature of the workshop, typically using the terms: 'getting involved' or 'getting to do stuff.' A number of interviewees said a positive aspect of the workshop was working in groups, or commented on how well their group worked together:

> Me and my group were working really well

> We were all working together as a team

Discussion

The study workshop was enjoyable and educational, a strong argument for increasing the use of drama in primary science. The majority of children expressed positive feedback about the drama theme, either because they enjoyed drama, its physical or participatory nature, or the investigative learning experiences. A high level of involvement and novel teaching activities are key factors for improving interest and attitudes in school science (Osborne, Simon, and Collins 2003). Drama satisfies both of these conditions without the logistical issues associated with out-of-school visits and fieldwork. This is not to suggest that drama should replace these important aspects of school science but rather that it can provide a valuable complement, enabling students to explore the culture of science through imagined contexts (Warner and Andersen 2004).

Andersen (2004) observed that students read about the discoveries made by historic scientists in a way that is disconnected from the actual world of scientific discovery. He proposed that process drama could be used to position learners in an authentic scientific scenario with instructional activities that resemble those of the professional scientist. Warner and Andersen (2004) put this into practice with a primary school level study based on process drama, in which pupils improvised roles as expert zoologists for a class investigation about snails. Children in the drama-based inquiry group performed better in post-activity assessment and were more motivated than children in the traditional inquiry control group.

Although the present study demonstrated the pedagogic value of a visiting theatre-in-education production, teacher training would allow drama techniques to be embedded into teaching practice. INSET training in drama techniques is provided by a number of theatre-in-education companies and there are existing guides to using drama techniques in the primary and lower secondary classroom (e.g., O'Toole and Dunn 2015). Key features of this workshop, which are believed to have contributed to its success, are described in Supplemental File 3.

The study also demonstrated that a drama workshop with experience of living plants is able to reduce plant blindness. Plant experiences in the workshop played a key role in enjoyment and learning and were responsible for the positive attitudinal change towards plants. The sensorial experiences and inquiry-based learning with living plants were highlights of the workshop. Whilst the outdoor environment is indisputably the best place to learn about plants, the reality is that children experience limited outdoor learning opportunities (Waite 2010). Children in this study claimed that they had outdoor nature study only once a year on average. Bringing native plants into the classroom broadens students' contact with plants and can serve as a valuable primer activity prior to fieldwork (Stagg and Donkin 2013). It may also increase children's attention to plants in the local environment, as comments from children in the study demonstrated. Potted native species are a valuable method of presenting the whole specimen, with the advantage that they can be maintained in a cold frame or sheltered position throughout the year, allowing for repeated use and seasonal observations.

Sanders (2007) notes the value of introducing people to plant ambassadors, species that are intriguing or particularly eye catching, as one route for increasing interest. The most memorable species in this study was undoubtedly the Brazilian giant-rhubarb (*Gunnera manicata*) with its 5-foot leaf and distinctive male flower spike. Of the native species, the most popular were pineapple-weed (*Martricaia discoidea*), with flowers that smell of pineapple when rubbed, fox and cubs (*Pilosella aurantiaca*), a very hairy plant, and Granny-pop-out-of-bed (*Calystegia sepium*), which ejects its corolla when squeezed.

Conclusion

A workshop based on process drama, incorporating role-playing and hands-on work with living plants, offers an effective learning environment in line with theories of embodied cognition. Moreover, the engaging and emotionally stimulating qualities of interactive storytelling are expected to support learning and promote positive feelings toward science. The present study found that participation in such a workshop led to measurable changes in children's knowledge about plant classification and their attitudes towards plants. The majority of children reported that the workshop was enjoyable and educational. The primary factors underlying these feelings were love of drama, the participatory nature of the activities, and the hands-on experience with plants. This study demonstrates that process drama can be a valuable educational tool for combatting negative attitudes towards science, in particular 'plant blindness.'

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3.3 Summary of Research Findings

All pedagogic approaches produced a measurable increase in cognitive learning, with an increase in affective learning in drama studies and a high level of learner enjoyment reported in many studies (Table 7). The thematic analysis identified a similar number of segments distributed across the three themes of multimodal, memorable and affective learning (Figure 4 below). The dominant subthemes were embodied learning, enjoyment-related content and cognitive load.

Citation	Main Findings
Stagg and Donkin (2013)	Text key, picture game and keyword mnemonics equally effective for learning; high enjoyment and motivation for all three methods.
Stagg et al. (2015)	The printed key was a more effective learning tool than the digital key. Key design and accessibility determined the efficacy of learning and level of enjoyment, rather than presentation medium.
Stagg and Donkin (2016)	Mnemonics were more effective for learning and generated higher enjoyment, compared to picture keys or card games. The card game produced a higher increase in learning than the key.
Stagg and Donkin (2017)	Digital key was a more effective learning tool than the field guide in one context, reverse was true in the second context. Design and quality of field guide was more important than presentation medium for learning and enjoyment.
Stagg and Verde (2019a)	Descriptive writing and drawing equally effective for learning; drawing captured more information and was more enjoyable than writing.
Stagg and Verde (2019b)	Interactive theatre was effective for learning and increased interest and positive attitudes for plants. Key aspects: thematic singing, humour, visual elements and art activities.
Stagg (2019)	Drama was effective for learning and increased interest and positive attitudes for plants. Key aspects: experience with live plants, physical drama games; participatory learning.

Table 7. Summary of findings in studies

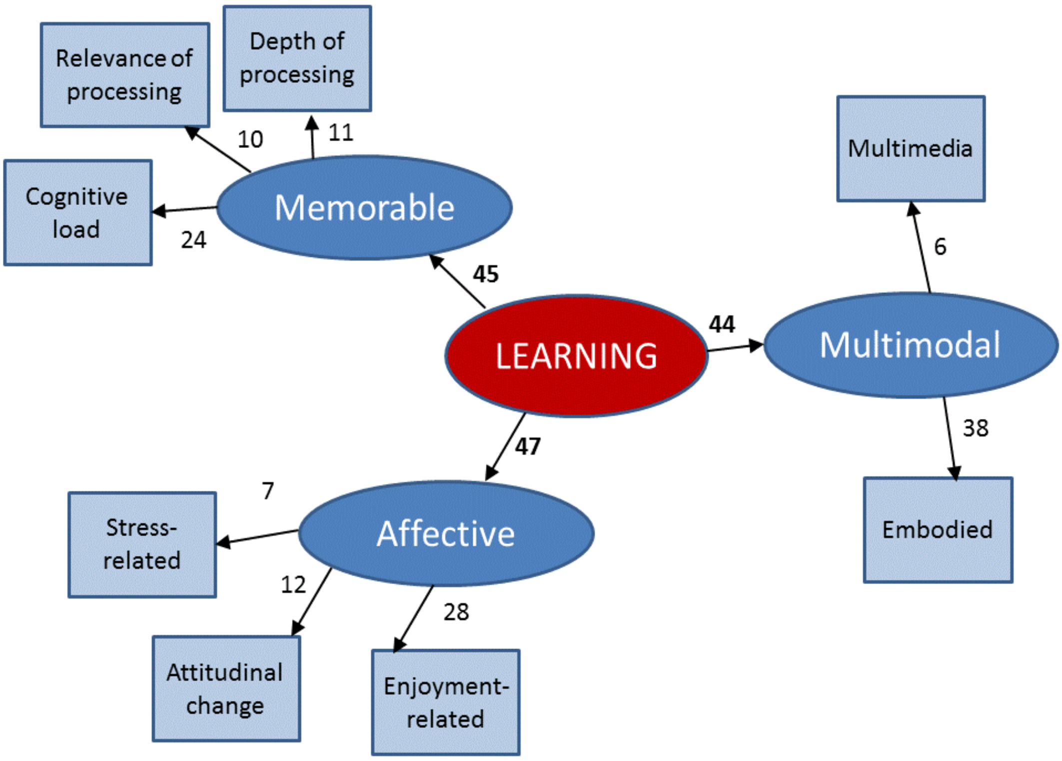

Figure 4. Themes in content analysis, showing number of text segments extracted per theme

4. DISCUSSION: EMERGING THEMES

4.1 The nature and extent of learning in this research

In this section I consider how and what my pedagogic approaches contributed to learning framed by theories of memory, embodied cognition, multimodal and emotional learning. I developed three related (and overlapping) models that demonstrated how theory and practice reduced plant blindness in the research (Figures 5 – 7). Models were derived from learner textual data and do not relate directly to Figure 4.

4.1.1 Active learning that promotes memorability

Meaningful processing

Craik and Lockhart (1972) showed that long-term retention of learning was mediated by depth of processing. For deep processing to occur, the learner must render the content meaningful, by making linkages within the content, linking it to prior knowledge, or to other information sources (Craik & Watkins, 1973). This process is called elaboration rehearsal and helps to create a richer background context to tie in the knowledge. Elaboration is a common feature of arts–based learning, where learners create an artistic representation in response to an information episode (Rinne et al., 2011). In Stagg and Verde (2019a), the creative writing exercise was the most relevant activity in this context, children described it as thought provoking and educational. The percussion and craft exercises were less meaningful as they required less elaboration on the information received. In Stagg (2019), children created their own plant names using the binomial system.

Scheiter, Schleinschok and Ainsworth (2017) demonstrated that producing a sketch benefited learning more than explanatory writing, following the reading of a science text. The authors concluded that drawing promoted deeper learning because learners must transform the focal material, thus requiring greater elaboration. Following this logic, a learning advantage might have been expected in the 2019a study for the writing strategy, as learners are transforming visuo-spatial information into verbal expressions but, in fact, there was no difference between approaches. One example of the elaborative nature of the writing was the variety of similes that learners used to describe morphological features, as a way of compensating for their lack of technical vocabulary.

In Stagg (2019), children participated in a drama game about explorers, after learning about Linnaeus's expeditions, another form of elaboration. Physically acting out material improved recall compared to reading, discussing or hearing the material, known as the enactment effect (Scott, Harris & Rothe, 2001; Senkfor et al., 2002). In the interviews, one third of participants described the physical drama elements as being directly beneficial to learning, mainly by making the content more memorable (examples in Figure 5 below). Feedback also suggested that the explorer game enabled children to imagine, or empathise with, the explorers' experiences. It is this aspect of enacting that Scott et al. believed was responsible for the memory advantage: people processed material more deeply if they could imagine what the social agents within it were experiencing.

Art and drama activities can also be considered from an embodied cognition perspective, based on Varela's et al. (2016) theory that learning is grounded in the body's sensorimotor systems, as well as the brain. In this context, learners are engaging sensorimotor functions in the meaning–making that leads to deeper processing (Rinne et al., 2011). The multimodal nature of encoding may also contribute to learning, as discussed in the following section.

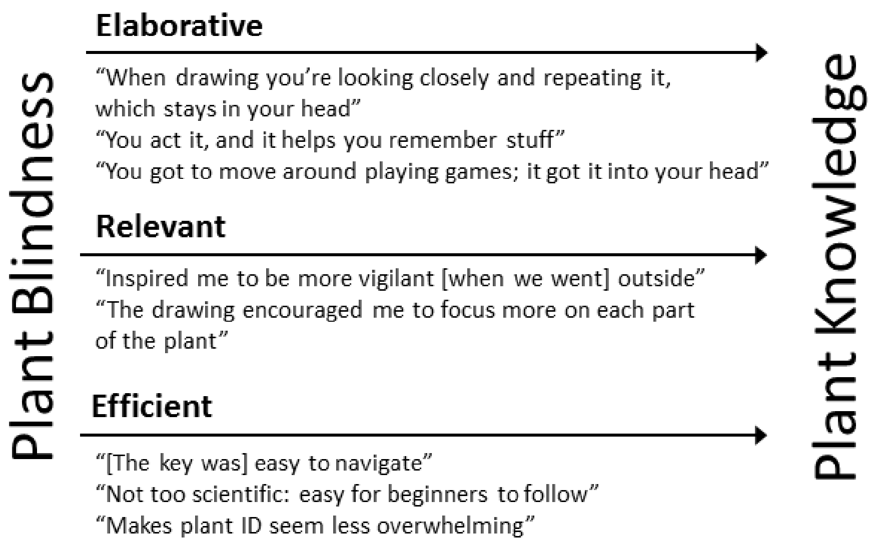

Figure 5. A model for reducing plant blindness using memorable learning (quotations are excerpts from questionnaires and interviews, in all studies)

Mnemonics (Stagg & Donkin, 2013; 2016) were elaborative because learners were required to generate mental images based on the statements linking species name to appearance. However, there was no evidence in the feedback that the memory advantage for the mnemonics was due to superior visualisation of species. Based on the enactment effect, the depth of processing could have been enhanced through learners miming actions in response to the statements. The learner–generated mnemonics required a greater depth of elaboration than the teacher-generated mnemonics but were more time–consuming to produce.

Elaboration is well-known to be time–consuming (Slamecka & Graf, 1978), so it is important not to disregard the related learning strategies of information repetition and retrieval (Hintzman, 2010; Roediger & Butler, 2011). Repetition was applied effectively in card games (Stagg & Donkin 2013; 2016) and a thematic song in Stagg and Verde (2019b), where the use of rhyming verse assisted recall (as also reported in Crowther & Davis, 2013). An example of retrieval in the 2019b study was the use of an interactive flower model, on ers assembled the reproductive parts.

Relevant processing

Morris, Bransford and Franks (1977) showed that memory performance was also modulated by how closely encoding conditions matched conditions for retrieval, which they defined as transfer–appropriate processing. Kiefer and Trumpp (2012) discussed the need for embodied learning to be based on relevant sensorimotor interactions in order to be effective.

Learning approaches for taxonomy in this research (apart from card games) were based on the handling and close inspection of live plants, which simulated the process of identifying a species in the natural environment (Figure 5 above). But there were some physical distractions apparent in instructional design, particularly for identification keys in earlier (2013–17) studies.

In Stagg et al. (2015), the desktop computer key involved multiple mouse clicking and page scrolling actions, which might have led to the low identification rate and high completion time. By contrast, paper and mobile computer keys could be positioned close to the plants and they relied on finger movements for navigation, thus providing more opportunity for plant handling and inspection. Feedback in Stagg and Donkin (2016) indicated that mobile computer keys still presented some sensorimotor distractions, due to the small screen size and screen reflectance, a similar result to Kissi and Dreesman's (2017) study.

Effective use of working memory

Processes that distract from learning can also be examined from the perspective of cognitive load theory. Sweller, van Merrienboer and Paas's (1998) cognitive load theory proposed that instruction is most effective when it is designed to make the best use of the limited working memory resources available for learning, with minimal distractions. In the key approach, the learner must use working memory to move between the different steps, as well as make sense of, locate and compare the identification cues described in the key. The key, therefore, presents an extraneous cognitive load in this context, meaning it reduces memory resources available for encoding (Sweller, 2010). Learning to use a key is invaluable for students intending to pursue the study of botany but could be considered superfluous for the task of introducing novices to plants (Kirchoff et al., 2014). The main priority of the taxonomic learning in my research was to promote plant recognition, as inattention to plants in the environment is a key factor in plant blindness.

Keys also possess a high level of element interactivity, meaning that multiple segments of information must be held simultaneously in working memory during processing (Sweller, 2010). Many keys present a split–attention effect, where learners must divide their attention between pictorial elements and text and mentally integrate the two (Kalyuga, Chandler, & Sweller, 1999). The text–based keys used in my 2013 and 2016 studies provided one strategy for avoiding this effect. By contrast, the mnemonics approach has low element interactivity because species are presented separately, with one or two segments of information per species.

Key usability (2015 and 2017 studies) could be regarded as a proxy measure of extraneous load. A key issue in these studies was the omission of 'pre–post' recall tests, meaning the effect of usability on memorisation was not measured. Navigability (the ease with which the user can move through steps in the key) and quality (choice and presentation) of differentiation cues were found to exert most effect on usability. The desktop computer key had the poorest navigability, reflecting the fact that computer keys were still in their infancy, in design terms, at the time of the study. The corresponding printed key featured a flow–chart format with high navigability. This format also allows for spatial integration of text and images, thus reducing the split–attention effect, explained above. The most effective cues were those that were easiest to understand, with descriptions and images that closely matched the specimen. In the 2017 study, the 'wildflower' app had higher usability than the 'winter tree' app because the participants found that the naturalistic character drawings were easier to match up to specimen character states than the simplistic diagrams in the latter.

Procedural familiarity in learning is also shown to reduce extraneous cognitive load (Tuovinen & Sweller, 1999), which may explain why the familiar formats of the card games in the 2013 and 2016 studies assisted learning. In the 2019a study, feedback indicated that learner confidence with writing or drawing determined the extent to which the respective task distracted from direct plant experience, which could explain why there was no significant difference in test performance for the two approaches.

Mnemonics convert information into a form more easily remembered than its original form, which feedback indicated was the reason for their efficacy. A design element contributing to the construction of mental models is called a germane cognitive load (Sweller, 2010). The mnemonics and key approaches directed learners' attention to reliable diagnostic characters, design elements that could also be viewed as germane loads. By contrast, card games, drawing and writing approaches relied on learners developing their own strategies for differentiating between species. Consequently, in the 2019a study, learners' written descriptions included a large number of inefficient differentiation cues (those with low inter-species or high intra–species variation) for example, leaf colour.

In the 2016 study, substantially more learners mentioned learning relating to diagnostic characters for the key compared to mnemonics and considered the key to be the most valuable approach for learning about plant identification. This finding highlights the value of keys in developing transferrable taxonomic skills, if not immediate recognition.

Whilst games and mnemonics were superior to keys in feedback and recall for the two experiments in the 2016 study, there was no significant difference between approaches in the 2013 study. It is possible that this latter result constituted a type II error (Xiaofeng, 2018, p. 1743) as this was a pilot study that served to refine experimental methods for subsequent studies. The most notable issue was that I did not alternate the combinations of plant groups and learning methods. The sample size was small and some participants highlighted the poor quality of specimens.

4.1.2 Multimodal learning

Mayer’s (2005) theory of multimedia learning proposed that instruction was more effective when based on both verbal (text, dialogue) and non–verbal modes, because it activated multiple sensory modalities and relied on active learning to reconcile the different sensory inputs. Like elaboration, the goal of instruction is to direct the learner into organising and integrating new information with existing knowledge and thus form new mental models. The drama production in the 2019b study was particularly replete in multimedia content, which, the evidence suggested, contributed directly to learning. The actors combined dialogue with music, physical theatre and visual props to communicate concepts and processes in reproduction. Interview data indicated that the most frequently recalled concepts were those with the richest communicative media. Many children attributed learning to the visual and demonstrative qualities, which is what can make drama so valuable for communicating abstract science concepts (Peleg & Baram-Tsabari, 2011).

Kiefer and Trumpp (2012) applied the idea of multimedia learning in an embodied cognition framework, encompassing all sensorimotor systems, not just visual and auditory ones. The authors argued that activating multiple modality–specific areas of the brain (areas engaged in perception or action) led to more extensive coding and, thus, enhanced memory. Direct encounters with plants can engage multiple senses, through sight, touch, taste, manipulation and smell, but characteristics of the plant, the learner’s expertise and learning approaches modulate the experience.

The mnemonics and keys in the 2013 and 2016 studies were based on standard morphological cues from Rose (2006) and other identification guides, which were predominantly visual. But the keys and mnemonics did feature some tactile cues, for example, the texture of trichomes or resin on leaf buds. Descriptive drawing and writing provided an immersive experience with plants but drawing would have unavoidably encouraged a focus on visual processing. Writing appeared to promote a broader range of sensory interactions, as indicated by some learners’ descriptions which referred to the tactile qualities of leaves and stems, such as pliability or textures. However, some learners indicated that drawing encouraged deeper observation than writing, meaning they either noticed more features or focused on each one more intensely.

Stagg (2019) focused strongly on multisensory experience and the drama narrative was based around a range of plants that children were encouraged to smell, feel and closely inspect. Plants with striking appearances, textures, odours or size were used to heighten the sensorial experience, as well as seed pods that made a noise when shaken. Two thirds of the children interviewed in Stagg (2019) referred to embodied experiences, principally olfactory or tactile, and how these had contributed to learning or enjoyment (Figure 6). Many children also mentioned the observation of plants using magnifying glasses as an important aspect of the embodied experience. Other studies have highlighted the importance of sensory appeal, for creating memorable plant encounters, for example, Nyberg, Brkovic and Sanders (2019).

Figure 6. A model for reducing plant blindness using embodied experience (quotations are excerpts from interviews) (Stagg 2019)

4.1.3 Emotional learning

Learning is more effective when it evokes emotions. Cognitive and emotional processes are highly integrated and emotional arousal activates the areas of the brain involved in the consolidation of long–term memories (McGaugh, 2004; Phelps, 2006). Positive affect relaxes learners, which makes them more receptive to learning, promotes sustained attention and creative thinking (Isen, Daubman, & Nowicki, 1987; Ryan & Deci, 2000).

The majority of children described the drama experiences as enjoyable, which directly influenced their attitudes towards plants (Figure 7 below). Perceived enjoyment of plants was one of the categories measured in the attitudinal questionnaires and significantly increased in 'pre-post' testing gains for both studies. Children felt enhanced appreciation for plants, as active and intelligent organisms (Stagg & Verde, 2019b) or through gaining an insight into their diversity and complexity (Stagg, 2019). Positive affect was linked to the intrinsic qualities of the drama or participatory activities, as well as singing and humour (Stagg & Verde, 2019b), and direct encounters with plants (Stagg, 2019). Many children stated that enjoyment facilitated learning in the two studies, either because it made the information content easier to learn or rendered it more memorable. Arts enjoyment is an important precursor for memory–enhancing approaches such as elaboration and enactment to be effective (Rinne et al., 2011). However, it is important to highlight that not all children found the drama to be a positive experience. There is the risk that such students felt excluded and would have lower self-efficacy or intrinsic motivation as a result (Isen & Reeve, 2005).

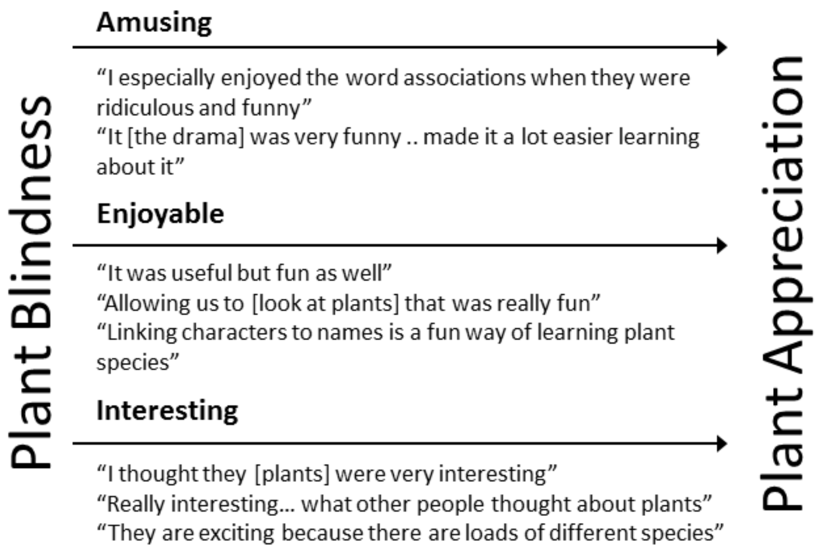

Figure 7. A model for reducing plant blindness based on positive affect (quotations are excerpts from questionnaires and interviews for the 2016 and 2019 studies)

Most children described the drama as humorous in Stagg and Verde (2019b), something which is known to improve retention (Sambrani et al., 2014). As Garner (2006) discussed, however, humour is a difficult emotion to arouse and the first version of the drama had to be revised because not all the humour was age–appropriate. Humour may generate a variety of psychological and physiological benefits in learning, for example, elevated endorphin levels (Berk & Nanda, 2006). Singing produces similar benefits (Kreutz et al., 2004) and half the interviewees described the singing as uplifting or relaxing. Similarly, half the interviewees in Stagg (2019) enjoyed the physical aspects of drama games, with some mentioning physiological benefits, for example, the opportunity to stretch stiff limbs. These findings highlight that the value of embodied experience lies not just in the effects of sensorimotor interactions on cognition but also, quite simply, the benefits that brief episodes of exercise confer.

Learners considered the mnemonics approach to be more enjoyable than the key activity (n=22) in Stagg and Donkin (2016), which could have contributed to the former's memory advantage (Figure 7 above). A few learners described the key activity as stressful and learners were often seen to be tense or anxious during these activities in Stagg and Donkin (2013; 2016). Many of the mnemonics were designed to evoke comical imagery, which learners were evidently amused by during the sessions. The majority of learners in Stagg and Verde (2019a) found drawing to be more enjoyable than writing. Whilst this difference did not influence subsequent test performance, it suggests that drawing is valuable for engagement, as discussed by Quillin and Thomas (2015).

Poor task performance is known to generate negative affect (Ainley & Hidi, 2014, pp. 205–227). The level of enjoyment was related to performance in identification tasks for the six different keys in my 2017 study. The time taken to complete the identification task did not appear to influence enjoyment particularly and, in fact, the most time–consuming key was rated as the most enjoyable because of its ease of navigation and presentation quality.

Learning that is compatible with learner cultures promotes enjoyment, and activities based on card games, role play and mobile devices are very familiar to British children (Joiner, Stanton & Luckin, 2003). However, what was clearly more important to learners in drama studies was how much the experience differed from the normal classroom culture. The drama activities were described as less sedentary, more interactive, less closely monitored (allowing more freedom) and less demanding of learners.

4.1.4 Limitations

The thesis research comprised small-scale studies, which were not designed to be part of one big study but pulled together post-hoc. A number of limitations are noted in each of the papers. They include relatively small-scale studies, the use of self-reported data and the short length of time of the interventions. Neverthless, the research made several relevant findings in spite of these constraints, confirming the validity and reliability of the experimental design, as well as the relative strength of the causal relationships under investigation.

The interventions were brief and the studies were undertaken with a broad age group, limited funding and, for the most part, reliant on opportunity sampling and volunteers. These issues have been taken into account when discussing the generalisability of the findings.

Some studies relied on self-reported measures of enjoyment, instead of using a multiple-item questionnaire about affective learning outcomes. Again, this issue was taken account of when discussing the findings.

The perceived novelty effect might have contributed to enjoyment and motivation, in the digital and drama-based interventions (Jeno et al., 2019). In spite of following the established advice, participants' responses in interviews and questionnaires may have been influenced by what they though the researcher wanted to hear (Fargas-Malet, McSherry, Larkin & Robinson, 2010).

4.2 Developing a pedagogy for botany to reduce 'plant blindness'

This section examines how learning may address plant blindness and the potential contribution of lifelong learning.

4.2.1 How this research helps to address 'plant blindness'

A leading reason for the inattention to plants is their lack of obvious movement. But plants are rich in perceptual characteristics, because of their sessile life–style. By learning to interact with plants using all the senses, these characteristics may serve to increase attention and interest (Figure 6 above). Lack of experience is a key impediment in plant blindness, so introducing learners to appropriate ways of examining and interacting with plants may encourage them to draw on these behaviours in the future.

Learners find botany a daunting subject, as the many studies on deficits in knowledge and understanding testify. This is a subject area with much to gain from effective memorisation strategies (Figure 5 above). Approaches that deepen information processing and minimise design–related distractions have been shown to improve learning. Multimedia learning can provide a richer, more memorable learning experience to address the low levels of interest in botany. Non–verbal modes of communication are particularly valuable for embodying abstract concepts to improve understanding.

A fundamental requirement for learning is that it is enjoyable, if it is to lead to sustained attention and interest (Figure 7 above). Arts–based and embodied approaches helped to foster physiological and psychological wellbeing. The perception of plants as inferior to animals (Table 1 above) cannot change without affective learning. Only an emotional shift can address the perception of plants as inferior organisms and foster a sense of appreciation for their qualities and abilities.

4.2.2 Lifelong learning

Almost a third of studies of plant blindness identified in the literature review were based on adults, so there was a sound argument for including adults, as well as children, in this thesis research. Plant knowledge is shown to play a key role in promoting pro–environmental behaviours in adults (Sat Gungor et al., 2018). Learning about plants can increase adults' public understanding of science (Watts, 2015), as well as broadening ecological knowledge (Pilgrim et al., 2007) and appreciation of nature (Clayton & Myers, 2009, pp. 54–72). Family members are known to be the primary source of children's knowledge about plants (Lindemann-Matthies et al., 2017) so addressing adult plant blindness might be as high a priority as improving plant biology education in schools. Furthermore, adults and children share many similarities as learners (Kerka, 2002), so the efficacy of teaching approaches may be examined just as valuably in either. Indeed, many of the pedagogic theories examined in this section were tested with adults (for example, Scott et al., 2001), and followed the same mechanisms in adults and children.

4.2.3 A pedagogic framework for botany

Figure 8 below presents a schematic representation for addressing plant blindness, based on the thesis research and review literature.

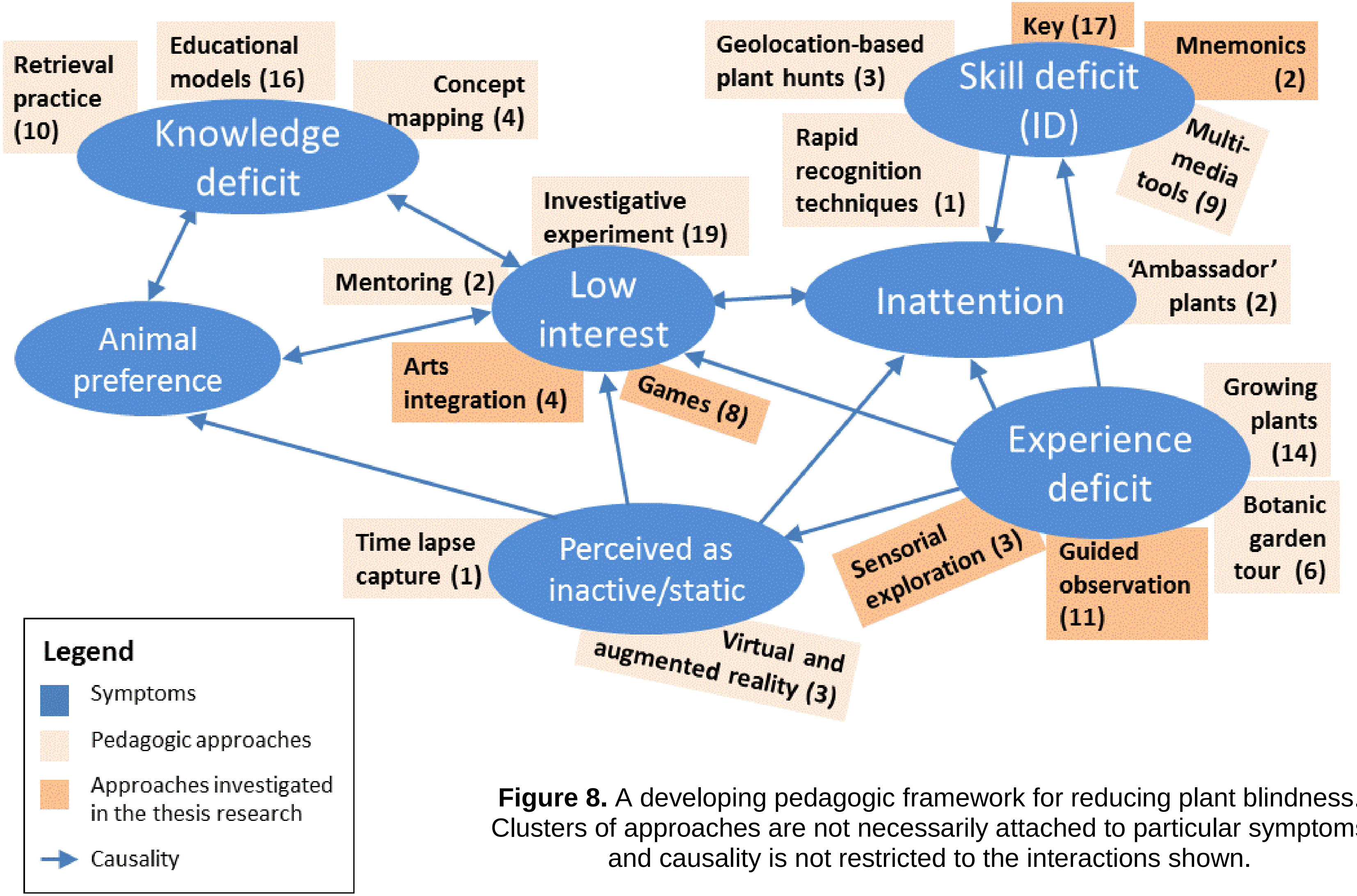

Figure 8. A developing pedagogic framework for reducing plant blindness. Clusters of approaches are not necessarily attached to particular symptoms and causality is not restricted to the interactions shown.

5. CONCLUSIONS AND IMPLICATIONS FOR THEORY AND PRACTICE

The key contributions to knowledge for the thesis research were as follows. The pedagogic approaches promoted learning through elaborative techniques, instructional tools with high usability, multimedia experiences and emotional wellbeing. The research highlighted that drawing and identification keys, which are the two most common activities in taxonomy, encouraged a focus on observation, to the detriment of other perceptual modes. Drama had the advantage that it is a learning mode based on embodiment. The research also drew attention to the range of physical and cognitive factors that may assist or impede learning.

In common with the reviewed literature, direct experience with plants was the keystone for addressing plant blindness in this research. Experiences benefit from being structured in a way that promotes a productive exploration of plants and minimises physical or cognitive distractions. Learning improves when it is enjoyable which helps to overcome the challenges botany faces.

I focused on brief interventions based on identification tools and physical exploration of plants in classroom settings to provide direct experience. Many interventions in the literature were longer in duration, allowing for investigative work based on plant cultivation, prolonged observation, fieldwork and visits to botanic gardens. In common with many existing studies, I examined the value of digital tools for botanical instruction, a branch of study that has advanced rapidly since my published work.

A major theoretical contribution of the thesis research is the application of memory theory to learning taxonomy, which few authors have investigated and which challenges the common assumption that species recognition is an automatic product of using an identification guide. The work has advanced our understanding of how the design of keys and mnemonics may promote retention when learning biological identification. The instructional tools also demonstrated that it is feasible to explore a range of teaching approaches with the minimal use of botanical terminology, known to be a barrier to interest development.

The thesis research builds on existing teaching methods to expand our knowledge of pedagogic strategies for plant blindness. In particular, the drama studies enhanced our understanding of children's attitudes to plants and the mechanisms by which a brief intervention can be used to positively impact these. Attitudes are an important element of plant blindness but the majority of educational studies focused on cognitive learning, with affective outcomes measured at best by one or two response items in a questionnaire.

What has emerged is a suite of brief, low cost tools that could be used alongside existing science teaching, specifically to address plant blindness, a persistent problem in many age groups. Bringing native plants into the classroom broadens students' contacts with plants. The pedagogical approaches developed in this research could serve as a programme of short, low cost encounters with plants in a classroom setting, ideally as preparatory exercises for fieldwork. The instructional tools could also be modified into a 'stand-alone' informal learning package, targeted at STEM clubs or field studies centres, for example. Consolidating the resources in this way would allow for a new, co-ordinated programme of research with a targeted audience of learners, which addresses the limitations of the thesis research. I am currently developing an online repository of thesis resources, on request from the Wildflower Society. In future work, I plan to apply the embodied approaches investigated in the thesis research, to a field context, in combination with open–ended investigative experiments.

6. APPENDICES

Appendix 1

Methods for the thesis literature review

The review process used in this study was developed from those of Bennett et al. (2005) and Davies et al. (2013), which are both educational in scope and based on the systematic review methods developed by The Evidence for Policy and Practice Initiative (EPPI) Centre for social science. A key advantage of the EPPI's methods is that they accommodate reviews of literature with a variety of research designs, as opposed to just the randomised controlled trials favoured by the medical field. Bennett et al (ibid.) presented a critique of the EPPI's methods and recommendations for applying these in an educational context. Davies et al. (ibid.) conducted a review of creative learning environments in education.

The following literature searches were conducted, to identify potentially relevant studies:

1. Searches using the scientific databases *Web of Science* and *SCOPUS* and the search terms listed in Table 1
2. Searches of leading research journals in science education (listed in Table 2) using select search terms from Table 1
3. Manual examinations of reference sections of key studies, conference proceedings and reviews (Table 3); a search of citing articles was conducted for pre–2010 studies

"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", "seaweed, education", "gymnosperm, education", "moss, education"

Table 1. Search terms for database searches

Journal of Biological Education
CBE Life Sciences Education
American Biology Teacher
Bioscience Education
International Journal of Science Education
Research in Science and Technological Education

Table 2. Research journals that were subject to additional searches

Allen, W., 2003. Plant blindness. *BioScience*, *53*(10), pp.926–926.
Balding, M. and Williams, K.J., 2016. Plant blindness and the implications for plant conservation. *Conservation Biology*, *30*(6), pp.1192–1199.
Nyberg, E. and Sanders, D., 2014. Drawing attention to the 'green side of life'. *Journal of Biological Education*, *48*(3), pp.142–153.
Patrick, P. and Tunnicliffe, S.D., 2011. What plants and animals do early childhood and primary students' name? Where do they see them?. *Journal of Science Education and Technology*, *20*(5), pp.630–642.
Sanders, D.L., 2007. Making public the private life of plants: The contribution of informal learning environments. *International Journal of Science Education*, *29*(10), pp.1209–1228.
Schussler, E.E. and Olzak, L.A., 2008. It's not easy being green: student recall of plant and animal images. *Journal of Biological Education*, *42*(3), pp.112–119.
Schussler, E.E., 2008. From flowers to fruits: How children's books represent plant reproduction. *International Journal of Science Education*, *30*(12), pp.1677–1696.
Strgar, J., 2007. Increasing the interest of students in plants. *Journal of Biological Education*, *42*(1), pp.19–23.
Sundberg, M., Antlfinger, A.E., Ellstrand, N.C., Mickle, J.E., Douglas, A.W. and Darnowski, D.W., 2002. Plant blindness:" We have met the enemy and he is us. *Plant Science Bulletin*, *48*(3).
Uno, G.E., 2009. Botanical literacy: What and how should students learn about plants?. *American journal of botany*, *96*(10), pp.1753–1759.
Wandersee, J.H. and Clary, R.M., 2006, September. Advances in research towards a theory of plant blindness. In *Proceedings of the 6th International Congress on Education in Botanic Gardens, Oxford University* (pp. 16–20).
Wandersee, J.H. and Schussler, E.E., 1999. Preventing plant blindness. *The American Biology Teacher*, *61*(2), pp. 82–86.
Wandersee, J.H. and Schussler, E.E., 2001. Toward a theory of plant blindness. *Plant Science Bulletin*, *47*(1), pp.2–9.
Wandersee, J.H., Clary, R.M. and Guzman, S.M., 2006. A writing template for probing students' botanical sense of place. *The American Biology Teacher*, *68*(7), pp.419–423.

Table 3. Studies that were subject to manual examination

1044 citations and abstracts were retrieved using the search methods. Titles and abstracts were screened against the inclusion criteria (Table 4), with examination of the full paper where this was not sufficient. 278 studies were identified for review. A randomly–selected sample of 2.5% was double screened by a colleague (Dr Michael Verde) as a reliability measure (Bennett et al., 2005). There was 100% agreement between the two authors for the screening of 30 papers, 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.

Category	**Criterion**
Topic	• Investigates one or more of the following traits in a sample of documents or human subjects: perceptions, attitudes, knowledge, understanding or experience specifically about plants. • Specific to plants, defined as species classified in the Eukaryote super–group Archaeplastida by Adl et al. (2005) • Specific to plants at the organism–level, as opposed to cellular, genetic or chemical components or plant aggregates (gardens, planting schemes or vegetation communities)
Article type	Original research published in *Scimago* indexed journals
Language	English
Experimental design	Based on empirical research using qualitative or quantitative methods
Scope	National and international research
Time period	Published between 1 May 1998 and 4 April 2020
Target groups	Any target groups except specialists in plant knowledge for example, professional botanists, herbalists

Table 4. Inclusion criteria for the review

The 278 studies were grouped by subject area, as defined by the title or 'aims and scope' of the journal and using the definitions in Table 5. Subject areas were as follows: biology education (134); ethnobiology (122); biological conservation (14);

‘other’ (8). ‘Other’ subject areas were landscape architecture, geography and linguistics.

Biology education – teaching and learning in biology, the study of living organisms. Includes teaching and learning in horticulture or agriculture (the science and practice of gardening and farming respectively). **Biological conservation** – the conservation (preservation, protection or restoration) of species, populations or ecosystems **Ethnobiology** – the scientific study or description of people’s traditional knowledge and customs about plants and animals

Table 5. Definitions for subjects (Lexico, 2019)

I conducted a thematic analysis to identify the main characteristics of each study, using the process described in Neuendorf (2019). I embarked on the task with an initial suite of *a priori* codes, which I then developed and revised upon close examination of a sample of texts. I consulted related publications or manuals where required, to inform this process. For example, codes for educational methods were initially based on Jeronen, Palmberg and Yli–Panula’s (2016) review of biology education but, upon application, I needed to modify some codes, delete others and generate new ones, to ensure that codes were specific to pedagogy in botany. This process was informed by the studies themselves. I also used Krathwohl (2002), Cohen, Manion and Morrison (2007) and Krathwohl and Anderson (2009) for developing and revising educational definitions. Codes for plant blindness were originally the symptoms defined by Wandersee and Schussler (1999; 2001), which were modified on application to produce a suite of concrete examples, which served to reduce ambiguity and overlap.

Each time codes were revised I returned to previously coded studies to check that no changes to coding were required. All codes were accompanied by a definition to minimise the potential for misinterpretation, ambiguity or overlap with similar codes. The subsequent suite of codes (86 in total) is shown in Tables 6 – 8. Each study was coded separately and the accompanying list of codes recorded in spreadsheets. An example is shown in Table 9. A randomly–selected sample of 5% was replicate–coded by a colleague (Dr Michael Verde) as a reliability measure. There was 100% agreement between the two authors for the coding of 10 papers, meaning it was not necessary to calculate an inter–assessor correlation coefficient. I subsequently calculated the frequency of all codes and the most frequently occurring codes informed the themes that are discussed in the Chapter text.

Code	Definition
Inv	Investigation of target population's knowledge, attitudes, perceptions, culture
Cont	Content analysis of secondary data (policy documents, research papers or educational media) to identify trends or bias
Expt	Experiment or quasi–experiment to test the efficacy of a novel educational intervention

Table 6. Codes for type of study

Code	Definition
Zoocent	Zoocentrism: a bias to animal species or topics compared to plants, in any biological context. Defined as a substantially higher coverage of animals than plants in media, curricula, instruction, research, conservation funding or management
XZoocent	No difference between the coverage of plants and animals in media, curricula, instruction, research, conservation funding or management
AniPref	A majority (>50%) express a preference (or higher positive affect) for animals compared to plants or mean preference/positive affect of the population sample is higher for animals than plants
XAniPref	A majority (>50%) state that they have no preference for animals compared to plants, or exhibit the same level of positive affect for both; no difference in preference or positive affect in the population sample for animals versus plants

AniRec	A majority exhibit superior rate of recall or detection of zoological information or images compared to plants or mean test performance of the population sample is higher for animals than plants
XAniRec	A majority show no difference in recall or detection of zoological information or images compared to plants
Vert	The zoocentric bias or animal preference is specific to vertebrates
Mam	The zoocentric bias or animal preference is specific to mammals
Bird	The zoocentric bias or animal preference is specific to birds
PosAtt	A majority (>50%) express a positive attitude or interest in plants or state that they would like to know more about plants/that it is important to know about plants; mean score of Likert questionnaire indicates a majority have positive attitudes to plants
NegAtt	A majority (>50%) express a negative attitude or poor interest; mean score of Likert questionnaire indicates a majority have negative attitudes to plants
AniAlive	A majority associate the concept of aliveness with movement or other behaviour or features that are characteristic of animals (animalistic)
DecInt	A decline in the interest in plants over time, as a programme of study (a substantial decrease in enrolment numbers in botany/plant sciences/plant biology over a stated time period), career (mean age of plant biologist has increased substantially over a stated time period or a majority ie >50% are <15 years to retirement) or other (frequency of terms relating to botany has decreased over a stated time period in a dictionary series)
Exotic	A majority (>50%) expressed a preference or more positive attitudes for exotic plants compared to other plant forms, superior performance in test for exotics compared to native plants
Tree	A majority (>50%) expressed a preference or more positive attitudes for trees compared to other plant forms, superior performance in test for trees compared to other plant forms
Gdn	Plant knowledge or positive attitudes towards plants are associated with a self–expressed interest in gardening, botanical conservation volunteering or pro–environmental behaviours
Plt neg	Botany is taught in an uninspiring way defined as: evidence of the low use of live plant material in instruction, or few opportunities to grow plants or observe their growth; the dominance of instructivist methods for plant topics or few 'hands–on' learning opportunities (defined as 'plant neglect')
Deficit	A majority (>50%) answer test question(s) incorrectly for a basic aspect of plant growth, development, reproduction, classification or ecology: in addition, the authors conclude that sample population exhibited poor or incomplete understanding for this topic, for what would be expected in that age group/educational stage
Poor ID	Poor plant identification knowledge as defined by majority of authors, for example, Bebbington (2005), Luckmann (2013) and Stagg and Donkin (2013): Mean ID test score <30% without prior instruction, a Majority (50%) scored <30% on test
ReasID	Reasonable plant identification knowledge: Mean ID test score 30 – 60 %
GoodID	Good plant identification knowledge: Mean ID test score > 60% *or* more than 18 useful plants identified per person
HighCollecID	The population sample can collectively identify and name uses for >49 plant species
Old>Yng	The level of plant knowledge is positively correlated with age; or for stratified age groups, the younger groups had less plant knowledge than the older groups. Age range in comparison is shown
F>M	Women or girls exhibit higher levels of plant knowledge than men or boys
Rur>Urb	Rural residents exhibit higher levels of plant knowledge than urban residents
EconID	Plant knowledge is negatively correlated with the mean wealth or development index of sample population
Fam>Sch	Family is a more important source of plant knowledge than school
Fam	Positive attitudes to plants were associated with having a parent or other close relative with positive attitudes towards nature
Knowl>nonEduc	The level of plant knowledge is negatively correlated with number of years of formal education; plant knowledge is higher in the illiterate members of the sample or those that did not attend school
FamKnowl	Plant knowledge is learnt orally from parents or grandparents
Comm>subs	Informants with commercial occupations had significantly lower plant knowledge than subsistence ones
ApplID	Plant knowledge is negatively correlated with number of household appliances (fridge, air conditioning etc)

Table 7. Codes for plant blindness

Code 1 (learning activity)	Code definition	Code 2 (setting)	Code definition	Code 3 (topic)	Code definition	Code 4 (outcome)	Code definition	Code 4 (target group)	Code definition
ART	Learning based on creative arts: (1) dramatic arts (which includes role playing or producing a creative gestural response), (2) visual arts (for example, crafts, painting, drawing), or (3) the literary arts, for example, composing story/poem, listening to a story	CLASS	Classroom or lecture theatre	TAXO	Taxonomy, classification	KNOW	Increase in knowledge (recall what was previously learnt – recite, reproduce, recognise) – Bloom lowest order cognitive domain	PRESCH	Pre–school age children
PAPKEY	Species identification using a paper–based key	HOME	Self–guided study, which typically occurs at home or in the campus library/study areas	ETHNO	Ethnobiology (human uses of plants)	COMPR	Increase in comprehension (focus on relating and organising the info previously learnt – able to explain/communicate concepts)	1Y	Primary school age children
COMPKEY	Species identification using a computer–based key	LAB	Laboratory	DEVEL	Growth and development	APPLIC	Increase in knowledge application (apply knowledge to new situations – this could include ID with novel sp and includes key use;	2Y	Secondary school age children
OTHERID	Other method for learning species identification eg picture cards, mnemonics	CAMPGD	Campus grounds, including greenhouse or gardens	REPRO	Reproduction	PSYC	Increase in psychomotor learning (the ability to use sensory cues to guide motor activity eg laboratory skills, plant cultivation	UG	Undergraduate students
COMPTOOL	Mulitmedia online teaching tool, generally for independent learning; includes online learning tools for learning of taxonomy	BOTGDN	Botanic garden (plant collection(s) open to the public)	PHS	Physiology (photosynthesis, gaseous exchange, water relations, tropisms, mineral nutrition, transpiration)	AFFEC	Increase in affective learning eg interest, attitudes, self–efficacy, motivation	PGCE	PGCE students

COMPOBS	*Subcategory of 'observation'* – using a mobile computer for field journalling eg recording observations, taking photographs and logging species location	HABITAT	An area of land composed of natural or semi–natural habitats	STRUC	structure and function	ENJPREF	Self–reported enjoyment, positive feedback or preference for a majority of the population sample	AD	Other adults
COMPOT	Other type of digital learning using desktop computers (instruction based on information technology; does not include routine use of IT that the learners have already mastered, for example, using a computer to write up experiment)	VISATT	Visitor attraction (s) not specific to plants, for example, museum, zoo	ECOL	Ecology (interaction of organisms with their environment)	OTLEARN	Other type of increase in learning, for example, non–plant subject domain		
COMPTOUR	Geolocated games, self–guided tours or treasure hunts around a garden with geolocated plants and information/quiz questions etc; often multi–media (audio, video etc)	OTOUT	Built environment, private gardens, public amenity areas	APPL	Applied plant science; industry and conservation	QUANT	Learning gain is statistically significant and based on pre post assessment design or expt treatment vs control		
PERSTOUR	A walk around an outdoor facility/garden, accompanied by verbal explanation from guide, eg class teacher, site manager			OTTOP	Other topic	POST	Learning gain is based on post assessment only		
GROW	*Subcategory of 'live'*– Plant cultivation, including seed germination and growth, gardening activities, treeplanting					SELF	Learning gain is based on self–reporting (ie opinion of learners)		
OBS	*Subcategory of 'live'* – Learning based on in depth/extended observation e.g scientific drawing, keeping a field or laboratory journal, writing a description or guided exploration. Often has function of teaching recognition of species identity or morphological features					QUAL	Learning gain is qualitative (non–numerical) or there is no statistical testing or outcome is expressed as a % majority of the sample of learners (eg 60% preferred x)		
GAME	A learning activity that is designed to promote enjoyment, or has enjoyment as one of its primary aims					NONSIG	No significant change in learning		

Table 8. Codes for educational attributes (code is only applied in the case of routine or incidental use of the learning activity; the activity has to be the main feature (or one of the main features) of the episode of learning)

Citation	Type of study	Plant blindness codes	Educational codes				
			Code 1 (learning activity)	Code 2 (setting)	Code 3 (topic)	Code 4 (outcome)	Code 5 (target group)
Torres–Avilez et al., 2015.	Inv	HighCollecID					
Kissi and Dreesman 2017	Expt		COMPTOUR, QUIZ ,COMPOBS,LIVE	BOTGDN	TAXO	COMPR, QUANT; NONSIG–AFFEC, NONSIG–APPLIC	2Y
Stagg and Donkin, 2013	Expt		PAPKEY, GAME,OBS,LIVE,OTHERID	CLASS	TAXO	QUANT, KNOW, ENJPREF	UG,AD
Burrows, Krebs and Kirchoff, 2015	Inv, Expt	PoorID	COMPKEY,COMPTOOL,QUIZ	HOME	TAXO	QUANT, APPLIC	UG

Table 9. Example of coded studies

Appendix 2

Example of the consent form used with adults (Stagg & Verde, 2019a)

DISCOVER WITH PLYMOUTH UNIVERSITY

OPAL EXPLORE NATURE

OPAL Botanical Identification Study

CONSENT FORM

Today you will identify and observe plant species and contribute to a research study about teaching botany. The session is 3 hours long and consists of an observation activity and two identification tests. You will be sent an optional repeat test in 2 weeks by email. OPAL is a partnership initiative funded by the Big Lottery, celebrating biodiversity, environment quality and people's engagement with nature.

The data may be used by Plymouth University for publication but no names of participants will be mentioned in the study. You are free to withdraw from the study at any time if you wish and all data relating to your participation in the study destroyed. All data will be stored securely, in accordance with the 1998 Data Protection Act

I have read the above, explaining the details of the study.

I understand that I am free to withdraw from the research at any stage, and ask for my data to be destroyed if I wish.

I understand that my anonymity is guaranteed, unless I expressly state otherwise.

I understand that the project researchers will have attempted, as far as possible, to avoid any risks relating to this study

Under these circumstances, I agree to participate in the research.

Name ……………………………………………………………………… Date ……………………………

Signature ………………………………………………………………………

The study is been co-ordinated by Bethan Stagg and Maria Donkin at Plymouth University.
bethan.stagg@plymouth.ac.uk; maria.donkin@plymouth.ac.uk

Appendix 3

Example of the parent information form used with minors (Stagg & Verde, 2019b)

DISCOVER WITH PLYMOUTH UNIVERSITY

Schumacher College

Blazing Tales

STORY OF A SEED

INFORMATION FOR PARENTS AND GUARDIANS

On [date] we will visit your child's school to perform a play called *Story of a Seed*, about plants and seeds. The play is part of a scientific study led by Schumacher College, investigating whether theatre is an effective educational approach for teaching science.

As well as participating in the one-hour play, your child will be asked to complete a 10 minute quiz about plants and seeds, before and after the play. The quiz is based on the National Curriculum and will allow us to determine whether the play was an effective teaching method. A randomly-selected sample of children will be invited to participate in a 10 minute interview with myself, later in class, about what they thought of the play. Audio will be recorded from the interviews but no photographs or video taken of children.

Data from quiz papers and interviews will not be used for any other purpose, apart from this study. The data may be used by Plymouth University and Schumacher College for publication but no names of participants will be mentioned. You and your child are free to withdraw from the study at any time and all data relating to your participation in the study destroyed. All data will be stored securely, in accordance with the 1998 Data Protection Act.

- If you are happy for your child to attend the play and participate in this study, you do not need to do anything
- If you would prefer your child to opt out, please contact your school office
- If you are dissatisfied with the way the research is conducted or wish to withdraw from the study and your data destroyed at a later date, please contact myself
- If you feel the problem has not been resolved please contact the secretary to the Faculty of Science and Engineering Human Ethics Committee (Plymouth University): Paula Simson 01752 584503

Kind Regards,

Bethan Stagg BSc MSc MRSB

Study Co-ordinator and Lecturer, Schumacher College
Email: bethan@schumachercollege.org.uk
Tel: 01803 847218/07866149773, *Schumacher College, Dartington, Totnes TQ9 6EA*

Appendix 4

Procedures for Personal Data Protection

The procedures used in this research for personal data collection, use, processing, storage and destruction complied with the Plymouth University Data Protection Policy (latest version 24/10/18) and the General Data Protection Regulation (GDPR) (EU) 2016/679).

Personal data was only collected in a paper format (questionnaires and forms); therefore no encryption or destruction of electronic data was required.

Collection

Data collection was limited to what was necessary for the purpose of the research:

- Questionnaires and forms only had the fields relevant and necessary for the purpose of collection and subsequent processing
- The required data collection was ascertained using predefined fields
- There were no 'optional' fields, as optional denotes that it is not necessary to obtain

Processing, Storage and Destruction

- Questionnaires and forms were stored in a secured lockable filing cabinet
- All personal attribute(s) were removed and replaced using a numbering system, when the data was entered on the computer. This pseudonymisation ensures that the data can no longer be attributed to a specific data subject through the remaining markers and attributes
- Questionnaires and forms were destroyed within 3 months of collection, by shredding

Appendix 5

Excerpts from the thesis content analysis

I conducted a thematic content analysis of the text–based, qualitative data that constituted the published papers in this thesis. I aggregated text segments according to a set of themes based on my theoretical framework. I subsequently reviewed themes to see if they provided a good fit for the data. Excerpts from the analysis are presented in Tables 1, 2 and 3.

When themes were reviewed for Stagg, Donkin and Smith (2015) (Table 1), the seven ‘usability’ text segments were incorporated into ‘cognitive load’ because usability is a measure of an instructional tool’s extraneous load. When themes were reviewed for Stagg and Donkin (2019a) (Table 2), the text segment “one third of participants described the physical aspects or drama as directly beneficial to learning, mainly in terms of benefits for information retention” was moved to the ‘depth of processing’ theme as this is an example of physical elaboration. When themes were reviewed for Stagg and Donkin (2019b) (Table 3), the ‘learner-compatible’ theme (defined as: “learning based on culturally familiar elements”) was discarded due to insufficient data (3 segments for the entire analysis)

Themes	Number of text segments	Examples
Usability	7	Nine students described the printed key as being ‘easy to use’ Eight students commented that: ‘some descriptions of/distinctions between characters were unclear’ for the printed key,
Embodied learning	4	Misidentification was high for *Plagiothecium undulatum* in the computer key. It was frequently mistaken as an acrocarp due to its large leaves and sparsely branched habit.
Cognitive load	3	A flowchart format is easy to follow and allows for immediate comparisons of similar species, whereas electronic keys rely on user selection for information displayed
Relevance of processing	2	The electronic key required physical navigation of up to sixteen mouse clicks and three page scrolling movements per species

Table 1 The content analysis for Stagg, Donkin and Smith (2015)

Themes	Number of text segments	Examples
Embodied learning	20	68 % of children mentioned embodied experiences in interviews. Of the native species, the most popular were pineapple-weed (Martricaia discoidea), with flowers that smell of pineapple when rubbed.
Enjoyment-related	10	In post-intervention questionnaires, 94% of children responded ‘yes’ to the question ‘did you enjoy the workshop
Attitudinal change	9	The remainder expressed an increased appreciation of plant complexity or plant science as a reason for their change in attitude
Stress-related	2	Several children also bemoaned the fact that they usually had pictures, models or discussion about plants instead of studying live ones
Depth of processing	1	Some of the perceived learning benefits of the activities came not from the physicality per se but from the feelings of empathy or appreciation they engendered in the participants

Table 2. The content analysis for Stagg and Verde (2019a)

Themes	Number of text segments	Examples
Attitudinal change	10	Plants were now perceived as adaptable, intelligent and intriguing
Enjoyment-related	9	The play was described as ‘funny’ by 80% of the children and 12% mentioned humour as their favourite aspect
Embodied learning	3	More than half of the interviewees mentioned the song when asked about aspects of the play that helped them learn.
Multimedia learning	3	The value of the non-verbal forms of communication for supporting learning, for example,percussion, physical theatre and stage props, was a theme that arose throughout the interviews.
Depth of processing	3	The song was considered helpful for learning because it was ‘catchy’
Stress-related	1	When asked how they thought the play compared to the classroom, many of the interviewees (41%) described the classroom in negative terms that described a teacher-centred, instructivist environment
Learner-compatible	1	Gabriel Oat mimes a kick-off at Wembley Stadium to highlight the importance of grass species to mankind, eliciting enthusiastic responses from the many football fans in the audience.

Table 3. The content analysis for Stagg and Verde (2019b)

7. REFERENCES

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