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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.

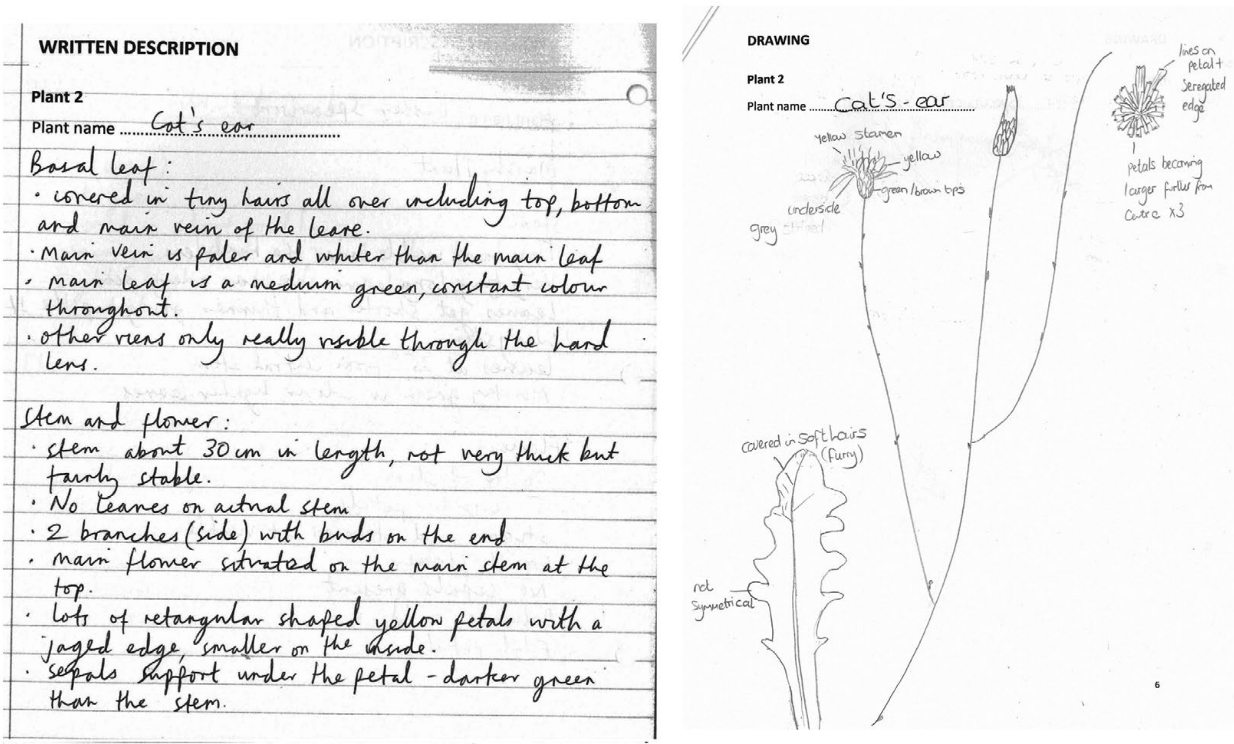
More diagnostic characters were recognisable in drawings than written descriptions for all eight study species (Figure 4). A repeated measures ANOVA confirmed that significantly more characters were produced in the drawing compared to the writing activity, $F(1, 41) = 71.28$, $p < .001$, $\eta_p^2 =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

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*).


WRITTEN DESCRIPTION

Plant 2

Plant name Cat's ear

Basal leaf:
· covered in tiny hairs all over including top, bottom and main vein of the leave.
· Main vein is paler and whiter than the main leaf
· main leaf is a medium green, constant colour throughout.
· other veins only really visible through the hand lens.

Stem and flower:
· stem about 30 cm in length, not very thick but fairly stable.
· No leaves on actual stem
· 2 branches (side) with buds on the end
· main flower situated on the main stem at the top.
· Lots of retangular shaped yellow petals with a jaged edge, smaller on the inside.
· sepals support under the petal - darker green than the stem.

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

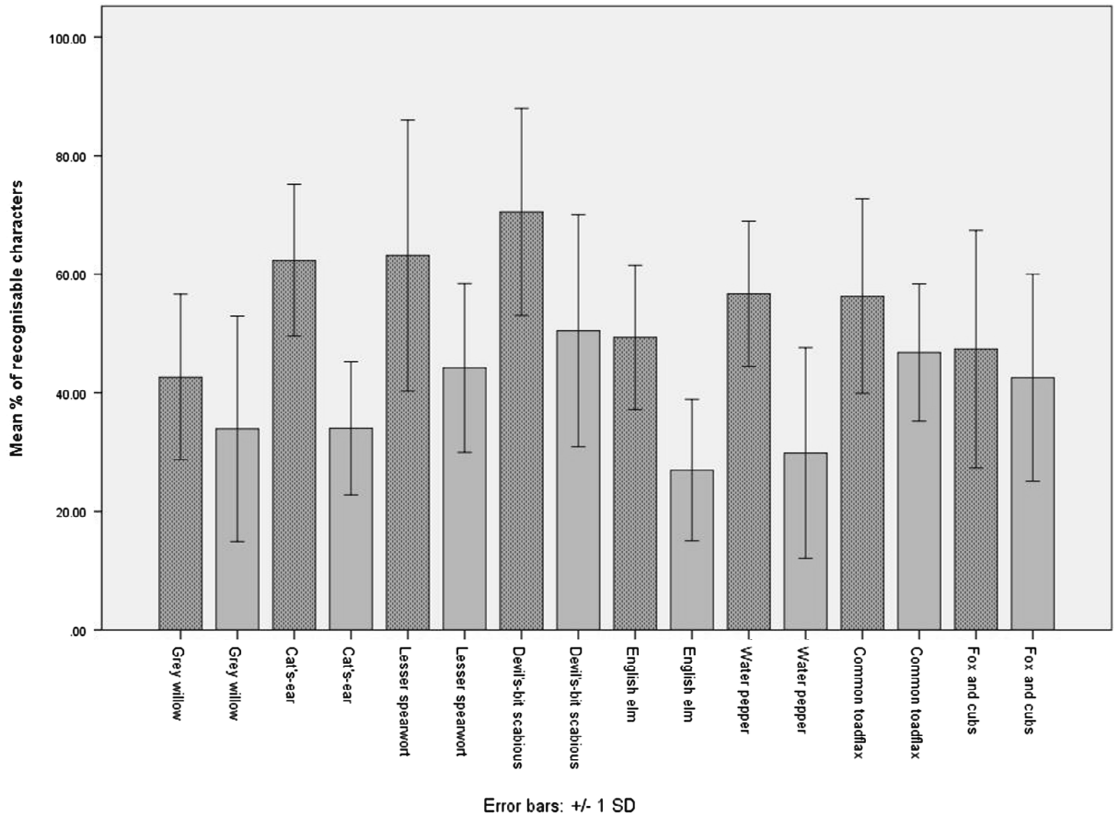


Figure 4. Comparison of the % rate of diagnostic characters identified in drawings and written descriptions (blue/stippling denotes the drawing activity; green/no stippling denotes the writing activity).

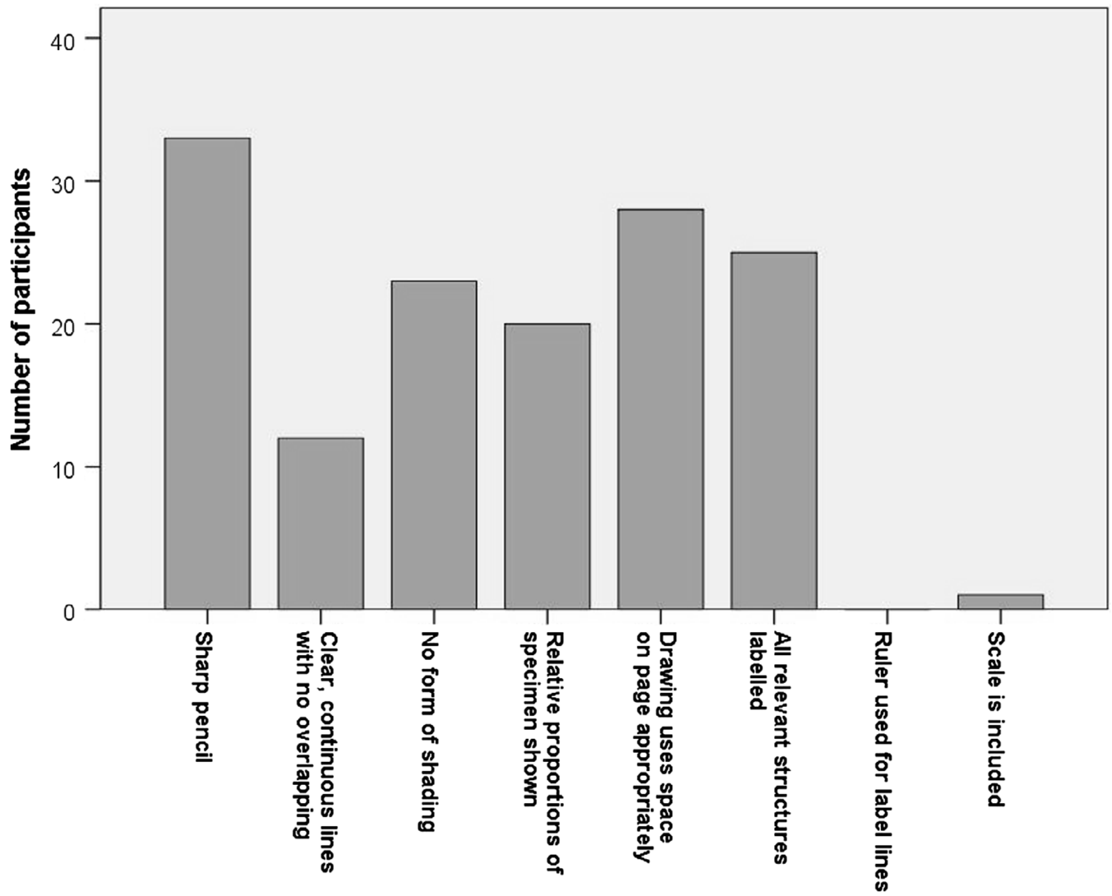


Figure 5. Evaluation of participants' drawings ($n = 43$).

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.

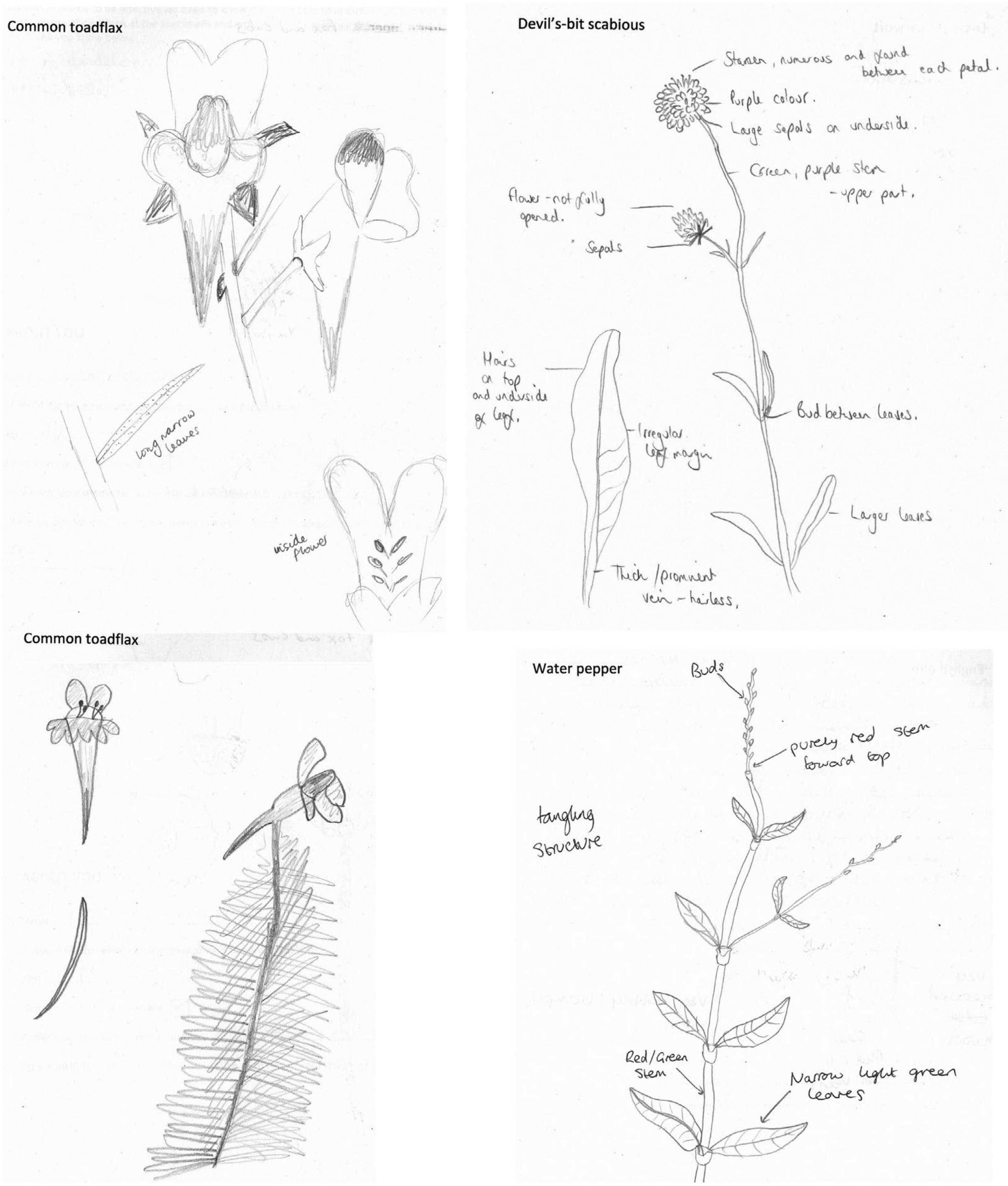


Figure 6. Examples of participants' drawing (drawings with low assessment scores on left; high scores on right).

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

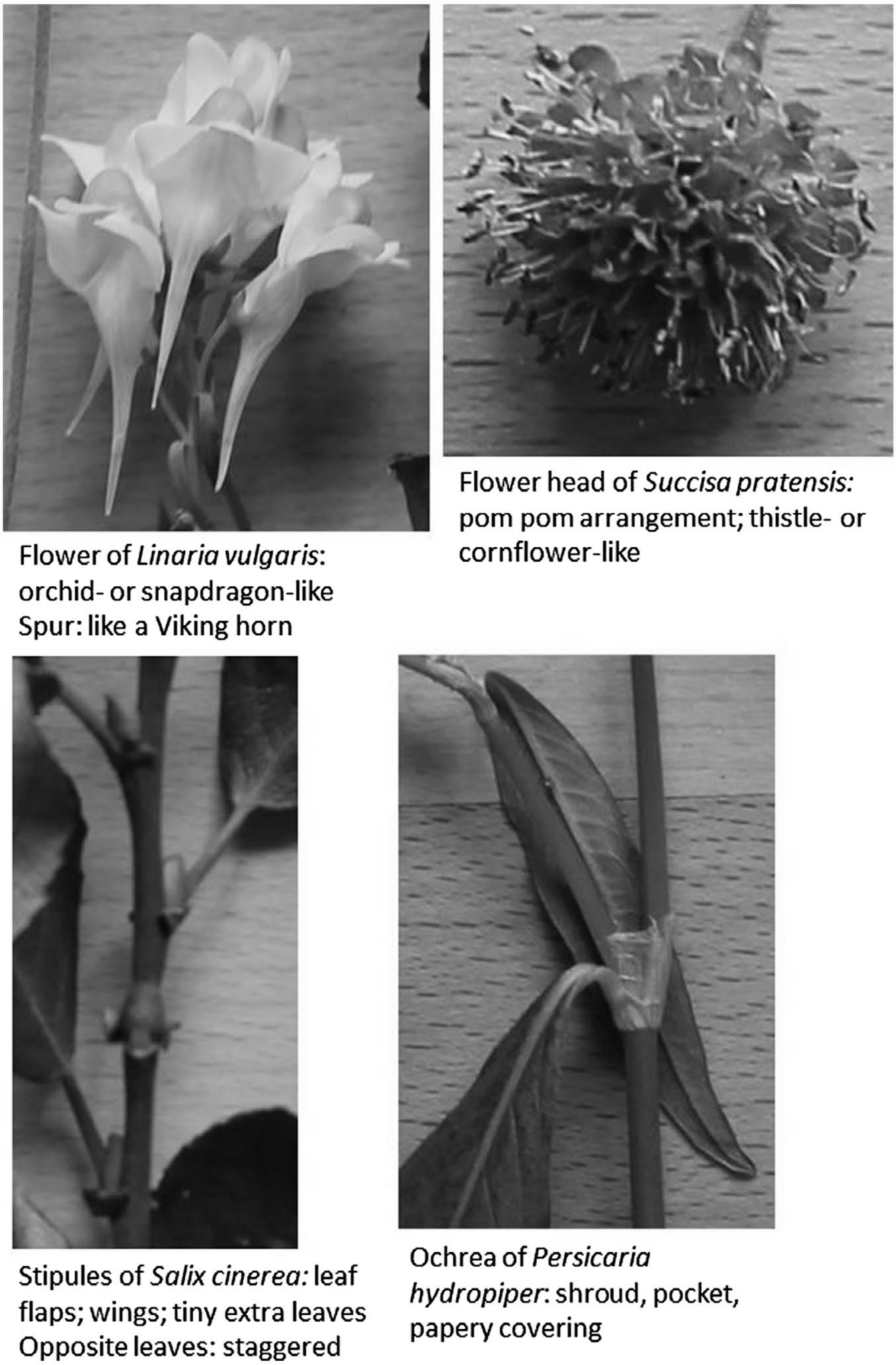


Figure 7. Examples of terms commonly used by participants for describing plant structures.

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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