Creating environment for students to make interdisciplinary competences in botany

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Abstract. The authors have developed an innovative botanical course that integrates genetic ideas into the botany curriculum. The process of choosing regional relics was conducted with the aim of illustrating the notions of full and partial dominion. This paper presents a novel phenetic approach for examining population genetic trends via the analysis of discrete alternative characteristics. In order to achieve this purpose, it is recommended to choose plant specimens from the local area that have significant morphological variety. This will allow students to actively participate in the collecting and study process during trips. The educational institution's curriculum integrates research components and cultivates the growth of mathematical statistical skills for the purpose of conducting quantitative analysis of results. The exploitation of currently available regional objects demonstrates the concept of the law of homologous series in genetic diversity and mutagenesis in plants. One of the recommended papers provides a detailed and concentrated overview of the developmental cycles seen in the primary plant categories. The investigation of hybridization in plants is often undertaken via the examination of this phenomena over a diverse range of plant species, including both widely dispersed wild plants and cultivated varieties. These botanical specimens have the capacity to engage in crossbreeding, leading to the emergence of hybrids that may occur either naturally or by deliberate human intervention.

1 Introduction

The field of botany, which comprises the scientific study of plants, has been generally recognised as a crucial area of scholarly exploration, having substantial implications for several sectors like agriculture, medicine, conservation, and climate change [1]. Given the continuous expansion of knowledge boundaries, it is becoming more imperative for students to cultivate interdisciplinary proficiencies in the realm of botany to effectively address intricate global issues [2]. This literature review investigates various tactics and approaches

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used in the establishment of educational environments aimed at fostering the development of transdisciplinary abilities within the realm of botany [3].

Acknowledging the significance of transdisciplinary skills in the domain of botany constitutes a vital basis for creating an educational environment that nurtures the development of these proficiencies [4]. The field of botany comprises a diverse array of scientific disciplines, such as ecology, genetics, microbiology, and chemistry, among others [5]. Therefore, students who possess transdisciplinary abilities are more equipped to tackle complex real-world difficulties in the field of plant sciences [6]. This section expounds upon the benefits of a multidisciplinary education in the realm of botany, including the augmentation of critical thinking skills, problem-solving capabilities, and adaptability [7].

The implementation of curriculum design and integration plays a crucial role in creating an educational setting that facilitates the development of multidisciplinary abilities within the realm of botany. The incorporation of elements originating from related disciplines such as biology, chemistry, and environmental science into the curriculum of botany might potentially enhance students' understanding of the interconnectedness inherent in the process of acquiring information. Various strategies are used to foster the development of these skills, including as the utilisation of case studies, engagement in interdisciplinary initiatives, and the implementation of team-based learning. Multiple research studies have shown that the engagement of students in interdisciplinary learning activities is correlated with a higher probability of developing a thorough understanding of the discipline of botany [8].

The development of diverse skills within the subject of botany is facilitated by the inclusion of experiential learning and fieldwork as integral components. By engaging in activities such as conducting botanical surveys in different habitats or actively participating in community-based research projects, students are provided with the chance to apply their academic knowledge in practical settings. Fieldwork is of utmost importance in the cultivation and enhancement of fundamental proficiencies essential for interdisciplinary methodologies, including the aptitude for observation, cooperation, and the ability to amalgamate knowledge from diverse sources [9].

In the present day, the integration of technology and the assimilation of data have become essential components in the domain of interdisciplinary abilities in the subject of botany [10]. It is crucial that students be given the chance to acquire knowledge with current technologies and procedures, including but not limited to molecular biology, remote sensing, and data analysis software. The integration of these technologies into the educational curriculum enhances students' research capacities and flexibility by enabling them to acquire skills in data collecting, analysis, and interpretation from diverse sources [11].

The formation of collaborative alliances with experts from many fields is an essential element in fostering interdisciplinary proficiencies within the realm of botany [12]. The promotion of interdisciplinary team formation among students, both inside and outside the academic context, has the potential to enhance the development of effective communication and collaboration skills [13]. This section highlights the importance of creating networks and cooperation with individuals and organisations that hold competence in related disciplines [14].

The use of suitable assessment and evaluation methods is essential in determining the effectiveness of educational efforts aimed at developing interdisciplinary skills in the realm of botany [15]. This section explores several assessment approaches and procedures, such as rubrics, portfolios, and peer evaluations that are proficient in accurately evaluating students' diverse competencies. Moreover, this study explores the challenges associated with assessing these skills and suggests alternate solutions.

2 Materials and methods

The initial courses given within biological faculties at colleges generally include the study of botany, which encompasses several aspects such as anatomy, morphology, and plant taxonomy. On the other hand, advanced courses in the field of biological sciences, such as genetics, are often undertaken in the latter phases of scholastic pursuit. The prominent workshop in the field of botany functions as an applied discipline that expands upon the fundamental information obtained in the core botany course. The workshop offers students a tangible application of their academic pursuits, including a sequence of laboratory experiments and hands-on lectures. Moreover, it is essential that the curriculum not just recapitulate the theoretical components of the course and serve as a vehicle for acquiring practical skills, but also serve as a medium for delving into wider biological fields such as genetics, ecology, and evolutionary studiesWithin educational institutions, the topic of general biology has several components. Among them, genetics stands out as a discipline that may be considered highly theoretical. This is mostly owing to its limited range of definable subjects available for inquiry and the reproduction of known hereditary patterns via experimental means.

Without a doubt, there is an evident discrepancy in the level of genetic research that has been undertaken on different organisms. In the present context, it is reasonable to use the phenetic technique, which entails the examination of population genetics patterns via the analysis of discrete alternative characteristics.

From our standpoint, the integration of genetic elements into botanical curriculum at universities and educational institutions will enhance the achievement of the following methodological goals:

1) Improving one's comprehension of core biological disciplines acquired via formal study in the field of biology.
2) To get a comprehensive understanding of a university-level course in fundamental biological sciences, such as genetics, it is crucial to recognise the need of exploring patterns of heredity and variability via the analysis of specific specimens from the fields of zoology or botany.
3) The objective of this work is to expand the range of organisms suitable for instructional and methodological purposes in the area of genetics, going beyond the conventional objects of genetic research.
4) The integration of indigenous plant species from specific regions into scientific education serves as a valuable approach for examining patterns of inheritance and basic concepts of population genetics.
5) The development of methodological skills in the actual implementation of interdisciplinary connections spans several facets of biology, as well as mathematical sciences.

This involves the development and mastery of abilities in solving algebraic problems, mathematical statistics, and processes related to digital data. Since the 1980s, population genetics has gained recognition as a key scientific and methodological framework for studying wild animals and plants. This methodology enables the pragmatic investigation of the interaction between genetics and evolutionary concepts, focusing specifically on population genetics and the genetic mechanisms that propel change within populations. Within the framework of a genetics curriculum, it is plausible to organise a methodical and concentrated examination of the life cycles shown by both higher and lower plants. This article aims to conduct a comparative analysis of the chromosomal sets found in plant species, focusing on those that exhibit different ploidy levels, including haploid, diploid, triploid, and dikaryon, during different phases of their life cycle. This technique is consistent with one of the laboratory tasks suggested for this course.

This study aims to investigate the relationship between theory and practise, as well as the possibility of confirming recognised genetic and evolutionary patterns in new research and educational settings.

6) This study aims to provide a comprehensive framework that offers methodological assistance to educators in designing and executing specialist genetics courses and workshops tailored for high school students. The primary objective of this framework is to augment educators' comprehension of botanical topics, include localised viewpoints into the instructional programme, and expedite the distribution of current knowledge within the realm of genetics. The proposed inclusion of the botany workshop component, intended as extra content for primary students with a solid understanding of broad biological concepts, will be included into the curriculum of senior courses at the school. The integration will be grounded on the preceding part on botany and the current investigation of genetics.

By using phenetic research approaches in the investigation of plant organisms, it becomes possible to establish targeted educational and research initiatives, resulting in the attainment of significant findings. To successfully undertake this task, it is imperative to possess the requisite skills of observation, a thorough comprehension of the morphology of specific plant species and taxa, the ability to discern both quantitative and qualitative traits within the framework of intraspecific variability, and access to a sufficient amount of information for statistical analysis.

In the context of our interdisciplinary workshop titled "Illustration of the patterns of heredity and variability in plant organisms," which is an essential part of a comprehensive botany workshop and is particularly suggested as an elective course for high school students in specialised educational institutions, we suggest the incorporation of the following laboratory exercises.

3 Laboratory exercises for students to make interdisciplinary competences

3.1 The significance of hybridization in plant selection

Objects: This list comprises a variety of plant species that possess the ability to undergo hybridization, either naturally or through human cultivation. Examples include Rubus loganobaccus, cultivated Fragaria ananassa, Prunus domestica, Brassica napus, Brassica napus var. napobrassica, Medicago sativa, Mentha piperita, Citrus paradisi, Citrus tangelo, Petunia nyctaginiflora, Canna, Malus domestica, Helianthus tuberosus, Alopecurus pratensis, Musa paradisiaca, Dahlia and Hibiscus.

Progress: The examination of hybridization among closely related forms in both natural and human breeding contexts is an applied facet of investigating the genetic criteria that define a species. Hybridization may be achieved by artificial means as well as through natural processes, independent of human involvement. Certain individuals are incapable of reproduction and are regenerated with each occurrence, while others have the ability to reproduce either sexually or asexually by vegetative means (in the case of plants). The potential for hybridization in plants surpasses that of mammals due to the phenomenon of polyploidy. Specifically, tetraploid allopolyploids in plants do not exhibit unpaired chromosomes during meiosis, hence expanding the range of hybridization possibilities. several intentionally derived hybrids, such as Mentha piperita and Fragaria ananassa, are absent in natural settings. Conversely, several hybrids emerged spontaneously and were subsequently cultivated by humans. Additionally, there are numerous instances when individuals are unaware of the hybrid lineage of certain crops, such as rapeseed or swede.

The approach to students' autonomous engagement with this subject matter may vary, depending on the instructor's preferences and the students' level of motivation. We provide a variety of alternatives for implementation.

1) Please provide a list of species that are capable of hybridization. Additionally, kindly offer to independently research information on the development of hybrids (both artificial and natural), their fertility, and any potential commercial uses.
2) I kindly propose to do an independent investigation to ascertain the upper limit of documented hybrids, including both natural and agricultural contexts.
3) Please include examples of hybrid forms seen during a trip or laboratory class, such as peppermint, rapeseed, and loganberry. Additionally, encourage students to independently explore and gather information on all documented hybrids, including those that occur naturally, those cultivated in botanical gardens, and those developed via breeding advancements.

In the context of knowledge monitoring, we provide the following information, acknowledging that it may not include all relevant aspects and should be complemented by the independent research efforts of peers or students using diverse contemporary resources [Table 1].

Table 1. Plants hybridization

№	Crossbreeding species	Name of the hybrid (if any)	Naturally or artificially obtained	Fertility
1	*Rubus idaeus* & *Rubus fruticosus*	*Rubus loganobaccus*	Naturally occurring, in regions where *Rubus idaeus* and *Rubus fruticosus* coexist.	The process of fruit and seed formation
2	*Fragaria chiloensis* & *Fragaria virginiana* (Both originate from Latin America.).	*Fragaria ananassa,* also known as the cultivated strawberry, is a cross between the Virginia strawberry *(Fragaria virginiana)* and the Chilean strawberry *(Fragaria chilensis).* This hybrid variety has been widely cultivated and is now cultivated on every continent.	Artificially obtained, lacking existence in natural settings.	It reproduces vegetatively with a moustache and does not cross with Eurasian strawberries.
3	*Prunus spinosa* & *Prunus cerasifera*	*Prunus domestica*	Hybrids are cultural inventions that do not exist in nature.	Produces normal seeds, however *Prunus* often grow vegetatively.
4	*Barbarea* & *Brassica oleracea*	*Brassica napus*	An amphiploid domesticated from nature	Due to a tetraploid set of chromosomes, the plant is fertile.
5	*Barbarea* & *Brassica rapa* (fodder turnip) and collard greens	*Brassica napus var. napobrassica*	Later grown from a natural rapeseed or turnip-cabbage hybrid with chromosomal doubling.	Beneficial because doubling the chromosomes yields a tetraploid set.

3.2 Finding population boundaries and analysing polymorphism using phenetics

Objects: The study encompasses an assortment of botanical specimens, including *Trapa* fruits exhibiting diverse shapes, various loosestrife plants with varying leaf whorl counts (ranging from 2 to 4 or more), *Cyclachaena xanthiifolia* leaves collected from different locations in the outskirts and streets of Pavlodar. *Trapa* fruits obtained from distinct floodplain reservoirs, larch cones, as well as leaves and catkins of warty birch sourced from different areas within the Pavlodar region (Pavlodar, Northeastern of Kazakhstan).

Progress: Initially, students are provided with a concise overview of the fundamental principles behind the phenetic method in the field of population genetics. Subsequently, they are encouraged to engage in independent research by studying pertinent scholarly literature. The use of genetically determined stable morphological features (phenes) has been a longstanding practise in the examination of spatial population structure, identification of population borders, and exploration of intrapopulation groups in many species of plants and animals. The study of population genetics in wild plants does not necessitate an extensive genetic mapping of every species under investigation, as this approach is often unfeasible and frequently unattainable. Consequently, A.V. Yablokov [1] proposes that all disciplines within the biological sciences adopt a genetic perspective, employing discrete genetically determined traits, akin to wearing genetic glasses, to facilitate their research. The phenogenetic technique has emerged as a prominent method for investigating several aspects of population genetics, ecology, evolutionary theory, and environmental monitoring, demonstrating clear advantages in these domains [1, 2, 8, 9]. Phen is a hereditary discrete alternative attribute that exhibits stability and repeatability.

1) Lythrum virgatum. The distribution of this particular plant species is extensive among the floodplain biotopes of the river. The Ertis River (Pavlodar, Northeastern of Kazakhstan) is often seen in close proximity to non-floodplain reservoirs. The prevalence of the common loosestrife is notably higher during periods of increased precipitation, whereas its population tends to decline during dry summers. The plant has a characteristic of having leaves arranged in a whorled pattern. When considering the counting of attributes, it is advisable to use the number of leaves in a whorl as a fundamental criterion, often ranging from 2 to 4 (sometimes beyond this range). In this particular scenario, it is essential to consider the quantity of leaves present in the whorl specifically inside the lower and middle sections of the stem. It is worth noting that the arrangement of leaves at the top may differ.

The students input the outcomes of their computations and statistical analyses into the subsequent table [Table 2].

Table 2. Polymorphism within phenetic method

Number of leaves in whorl	2	3	4	More than 4
Absolute number of plants with this trait				
Proportion (with representativeness error)				

The form of the stem is another noteworthy characteristic, exhibiting variations ranging from tetrahedral to hexagonal and spherical in different individual specimens. In this instance, it is advisable to evaluate the stem's morphology at its midpoint, since the lower portion may exhibit deformities due to the presence of coarsened grassy shoots, while the upper portion is excessively slender, making accurate assessment of its shape in a transverse section challenging. The students input the outcomes of their research and calculations into the subsequent table [Table 3].

Table 3. The form of the stem

Stem shape	Tetrahedral	Hexagonal	Rounded	Other
Absolute number of plants with this trait				
Proportion (with representativeness error)				

In regions where *Lythrum virgatum* is absent, although the *Lythrum salicaria* is present, research may be conducted using this particular plant species (which has the same genus and exhibits similar variations in leaf whorl count and stem cross-sectional form). There are notable distinctions between *Lythrum virgatum* and *Lythrum salicaria*, mostly in terms of their physical characteristics and ecological preferences. *Lythrum virgatum* is characterised by its pubescent stem and leaves, which are covered in fine hairs. Additionally, it has a greater tolerance for drier environmental circumstances compared to *Lythrum salicaria*.

2) Lysimachia vulgaris. Often seen botanical species found in floodplains, arid meadows, and forested valleys. Typically, the flowering period of this organism occurs in the month of June. The collection of the vegetative components essential for conducting phenetic investigations may be undertaken between the months of May and September.

The students input the outcomes of their computations and statistical analysis into the subsequent table [Table 4].

Table 4. Number of leaves in whorl

Number of leaves in whorl	2	3	4	More than 4
Absolute number of plants with this trait				
Proportion (with representativeness error)				

3) ***Cyclachaena xanthiifolia*** is a prevalent botanical nuisance found in both natural and human-influenced environments across the Pavlodar area. The leaf blades of *Cyclachena* exhibit diverse morphological characteristics, which may serve as phenotypic markers for investigating the level of isolation among *Cyclachena* populations residing in various habitats or at the periphery of urban areas.

The students record the outcomes of their computations and statistical analyses in the following table [Table 5].

Table 5. Leaf shape of Cyclachaena xanthiifolia

Leaf shape	Whole	Wavy	Lobed	Deep carved
Absolute number of plants with this trait				
Proportion (with representativeness error)				

4) Betula pendula. In the Northeastern Kazakhstan seen in the formation of natural steppe forests, as well as in the natural forests of the Kazakh Upland (Bayanaul). Furthermore, silver birch is widely distributed throughout many kinds of artificial forest plantations in the region.

Research on phenogenetics in populations of warty birch and downy birch has been conducted since the 1980s. The user has provided a numerical range of 8 to 9. In their study, Mamaev and Makhnev (1982) classified several leaf phenotypes seen in populations of warty birch. These phenotypes included round-narrow-angled, round-wide-angled, narrow-truncated-wedge-shaped, wide-truncated-wedge-shaped, and heart-shaped leaves, each occurring with varying frequency.

The authors of this study discovered many leaf types in downy birch, including diamond-shaped, ovate-diamond-shaped, ovate, widely ovate, oval, and heart-shaped.

Based on our empirical findings, it has been found that silver birch *(Betula pendula),* often known as warty birch, has a diamond-shaped leaf morphology in several natural and artificial plantations within the Northeastern Kazakhstan. This particular leaf shape, previously documented only in downy birch (*Betula pubescens),* is an additional characteristic to the leaf blade phenotypes described in existing literature.

The acquisition of laboratory materials is anticipated to occur via field trips and excursions outside of the immediate vicinity, as well as through focused outings inside the city and the organisation of collections in other towns within the Northeastern Kazakhstan, including both students and staff members. In order to accomplish this task, it is necessary to select 1-3 leaves exhibiting the most distinctive shape from each individual tree. These selected leaves should be carefully placed in individual envelopes to facilitate the drying process and prevent the occurrence of moisture-induced decay. It is advisable to utilise envelopes constructed from filter paper to ensure optimal preservation conditions. It is important to note that this selection process should consider the fact that leaves originating from the same tree possess identical genotypes.

Subsequently, under controlled laboratory circumstances, students ascertain the morphology of the leaf blade, categorise it according to established hair dryer classifications, and record the data in the corresponding accounting records. In the event that the morphology of a leaf does not resemble any known leaf shapes, a novel hair dryer is characterised and its stability, or repeatability, is assessed. Additionally, the frequency of occurrence across various birch populations is quantified.

The students input the outcomes of their computations and statistical analyses into the subsequent table [Table 6].

Table 6. The shape of the leaves of *Betula pendula*

Betula leaf shape	Round-narrow-angled	Round-wide angle	Narrow-truncated wedge-shaped	Wide-truncated wedge-shaped	Heart-shaped	Rhombus-shaped
Absolute number of plants with this trait						
Proportion (with representativeness error)						

3.3 Plant life cycles and chromosome sets

Objects: The vegetative body of diverse organisms includes green and charophyte algae, mosses, pteridophytes, horsetails, gymnosperms, angiosperms, as well as other forms of gymnosperm and flowering plant seeds. Additionally, fruiting bodies of fungi and the banana, which is the only natural triploid, are also part of this category.

Progress: When working with objects, students update the life cycles of various groups of plants, sorting the collected parts of higher and lower plants according to their chromosome set. Such combined laboratory work with elements of genetics and evolutionary teaching makes it possible to include information on botany, in particular, knowledge of the life cycles of the main groups of plants. The process of acquiring and enhancing such knowledge may present itself as intricate and fiercely contested endeavours, often seen in academic competitions such as topic Olympiads in the field of biological studies. One of the jobs that we devised was metaphorically referred to as “Cytological View”. The participants are provided with plant and mycological specimens that possess varying arrangements of chromosomes. It is important to categorise them into distinct categories based on their karyotypes, which refer to the number of chromosomal sets present in plants or their specific developmental phases. This assignment assesses one's understanding of the life cycles of plants across all taxonomic groups. This document provides a concise overview of the current state of knowledge across several disciplines pertaining to lower and higher plants [11, 12], within the context of a competitive academic environment.

If the job is executed accurately, the arrangement of items will exhibit the following distribution [Table 7].

Table 7. "Cytological View"

№	Karyotype	Objects	Selection rationale
1.	Haploid	Vegetative body of mosses, charophyte and filamentous algae, prothallus of fern (*Dryopteris)*	Mosses are haploid (only the capsule is diploid), charophytic and filamentous algae are haploid throughout their lifetimes, and the zygote is diploid. Fungi have haploid prothallus.
2.	Diploid	Spring and summer shoot of *Equisetum fluviatil*e, *Pinus* branch, *Ephedra*, *Betula* branch	Horsetails, gymnosperms, and angiosperms have diploid sporophytes that dominate the life cycle.
3.	Triploid	Banana *(Musa paradisiaca)*	Bananas are the only natural triploid that reproduces vegetatively without seeds.
4.	Dikarion	Boletus and fungus fruiting bodies	In basidiomycetes, including holobasidiomycetes, the binucleate stage (dicaryon) prevails.
5.	Diploid plus haploid	*Pinus* seed, *Pinus sibirica* nut, Семя сосны, кедровый орех, fern frond with spores, *Salvinia* sporophyte with developed shoots.	Gymnosperm seed embryos are diploid, whereas endosperm is haploid from megaspore tissue. Pteridophytes have diploid sporophytes and haploid spores. Both micro- and megaspores on the sporophyte plant generate haploid *Salvinia* shoots.
6.	Диплоид плюс триплоид	*Triticum aestivum, Oryza sativa seed*	Double fertilisation produces flowering plant diploid embryo and triploid endosperm.
Note: Students fill in the marked area within the lab work			

4 Conclusion

In summary, the establishment of a conducive setting that fosters the cultivation of interdisciplinary proficiencies in the area of botany is of utmost importance in equipping students with the necessary skills to effectively tackle intricate issues within the realm of plant sciences and its associated disciplines. This manuscript has underscored the significance of interdisciplinary education, curriculum design, experiential learning, technology integration, collaboration, and evaluation in promoting these abilities. In order to adequately prepare next botanists for the challenges posed by a dynamically evolving environment, it is essential for educators and academic institutions to persistently explore novel approaches and modify their instructional techniques. Additional investigation is required to delve into the enduring effects of interdisciplinary instruction in the field of botany and to establish optimal strategies for its integration in various educational environments.

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