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An Overview of Teaching Insect Morphology and Taxonomy with Open Educational Resources (OERs): Global Perspective

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Abstract:

Open Educational Resources (OERs) have revolutionized science education, especially in fields like entomology where high-quality photos, interactive modules, and taxonomic keys are crucial. The use of effective teaching materials is necessary because insect morphology and taxonomy offer a strong foundation for comprehending insect biodiversity, ecology, and pest control. The effectiveness, utility, and pedagogical integration of open educational resources (OERs) for teaching insect morphology and taxonomy are assessed in this study, which also highlights gaps and suggested future paths. The study includes a complete evaluation of the platforms that are available, such as Lucid Keys, Morph Bank, i Naturalist, Bug Guide, and others, and summarizes research from government databases, scientific publications, and educational libraries. In order to improve entomology teaching outcomes, the study also emphasizes the necessity of localized, bilingual, and curriculum-aligned OERs.

Keywords: Digital Pedagogy, i Naturalist, Visual Learning, Interactive Tools, Bug Guide and Morph Bank, and Entomology Education

1.Introduction

Taxonomy and Insect morphology are two of the most important aspects of entomological research. By providing a framework for naming, classifying, and identifying insects, taxonomy promotes biological discipline research and communication. Triple horn and Johnson (2005) and Grimaldi and Engel (2005) assert that morphology—the study of insect form and structure—offers important insights on insect adaptations, ecological roles, and behaviors. A strong understanding of taxonomy and precise morphological identification are becoming more and more important as entomology extends into practical disciplines including pollination ecology, vector control, integrated pest management (IPM), and biodiversity conservation (Gullan & Cranston, 2014).

Open Educational Resources (OERs), or teaching and learning materials that are freely accessible and openly licensed for usage, have emerged as powerful tools for enhancing scientific education in the twenty-first-century educational landscape. UNESCO (2012) defines OERs as "teaching, learning and research materials in any medium, digital or otherwise, that reside in the public domain or have been released under an open license permitting no-cost access, use, adaptation and redistribution by others." These tools have upended traditional instructional paradigms, especially in disciplines that require access to specialist material and are rich in content and visuals (Hilton, 2016; Wiley & Hilton, 2018).

Physical resource availability issues in entomology education, such as field trips, taxonomic keys, curated insect collections, or dissecting microscopes, have historically led to disparities in learning environments, especially in developing nations and remote locations (Minelli, 2020). As digital education has grown in popularity, open educational resources (OERs) have emerged as a viable way to democratize access to entomological knowledge by offering interactive taxonomic keys, high-resolution photos, annotated diagrams, 3D models, virtual dissection tools, and citizen science platforms (Nugent & Lear, 2020; Blagoderov et al., 2012).

Additionally, technological developments in e-learning, such as augmented reality (AR), virtual reality (VR), artificial intelligence (AI), and mobile-based microscopy, have increased the opportunities for teaching insect morphology and taxonomy through OERs (Ziegler et al., 2021; Bowman et al., 2020). Repositories like Morph Bank, Bug Guide, Lucid Central, iNaturalist, and Encyclopedia of Life (EOL) show how curated, crowd sourced, and publicly available entomological knowledge is changing educational frameworks (Walker, 2010; Marshall, 2017; Winker, 2022).

The need for blended learning strategies that incorporate open educational resources (OERs) into entomology instruction to improve student engagement, practical comprehension, and critical thinking skills has also been brought to light by recent curriculum reforms in biological and agricultural sciences, such as those carried out by the National Agricultural Higher Education Project (NAHEP), the Indian Council of Agricultural Research (ICAR), and the U.S. National Science Foundation (NSF) (Yadav et al., 2022; Sharma et al., 2021; Hilton et al., 2014).

A number of issues persist despite the enormous potential of open educational resources (OERs) in entomology, such as inadequate contextualization for local fauna, poor integration with formal curricula, a lack of resources in multiple languages, a lack of standardized quality control, and technical challenges faced by instructors in rural institutions (Baas et al., 2019; Trotter, 2017). As a result, a thorough assessment of the current OER environment is required, especially in relation to insect morphology and taxonomy.

2. Concept of OERs in Biological Sciences

The idea of Open Educational Resources (OERs) in the biological sciences is founded on the worldwide educational reform movement, which aspires to enhance equity, accessibility, and creativity in teaching and learning. Open educational resources, or OERs, are materials that are freely available to the public and openly licensed for use in research, education, and learning. UNESCO (2012) states that OERs can be maintained, reused, altered, remixed, and redistributed. The "5Rs" of OERs are a common term for this paradigm (Wiley, 2014). Open educational resources (OERs) offer a potent substitute for costly textbooks, proprietary software, and institution-specific specimen collections in the biological sciences, where learning primarily depends on accurate representation of complex structures, dynamic processes, and substantial observational data. In order to promote deeper engagement, lower expenses, and enable flexible learning environments, biology educators are rapidly integrating open educational resources (OERs) into their curricula due to the rapid advancements in digital pedagogy and the global drive for open science (Hilton, 2016; Baas et al., 2019).

Students must engage with anatomical system diagrams, physiological process films, ecological survey statistics, and species photos required for taxonomy and systematic since biology is a visual and participatory science. Thus, it has been demonstrated that open educational resources (OERs) like digital atlases and simulation software significantly improve learners' autonomy and conceptual clarity, Interactive 3D models and virtual laboratories (Ziegler et al., 2021; Bowman et al., 2020). For instance, compared to static textbook images, platforms such as HHMI Bio Interactive and Bio Render provide openly accessible tools and animations that simplify cellular systems and genetic processes (Belcher et al., 2020).Repositories like as the Open Stax Biology textbook and i Biology video courses, which are used by students and educators worldwide, provide high-quality, peer-reviewed, open-access content in molecular biology and genetics (Green et al., 2018).

Additionally, digital microscopy and photo databases such as Morph Bank and Visible Body are enabling the remote examination of biological material software. According to current pedagogical standards in both high school and higher education, this offers an immersive learning experience (Blagoderov et al., 2012; Winker, 2022).

In addition to delivering material, open educational resources (OERs) in biology facilitate inquiry-based and constructivist learning methods by enabling students to engage in citizen research, taxonomic identification, virtual dissection, and data annotation (Nugent & Lear, 2020; Tillinghast et al., 2019). In subjects where field-based experiences are traditionally prized, such as entomology, botany, and ecology, these interactive possibilities are highly valuable. Through initiatives like iNaturalist and eBird, students may contribute to actual biodiversity data while learning identification, categorization, and ecological monitoring—all crucial biology education skills (Sullivan et al., 2014; Nugent & Lear, 2020). Moreover, in countries where laboratory equipment and specimen collections are restricted or underfunded, OERs bridge the gap between content-rich education and learner accessibility, leveling the playing field for students across socioeconomic strata (Sharma et al., 2021; Baas et al., 2019).

The National Mission on Education through ICT (NME-ICT) in India, MERLOT Biology in the USA, and the Open Education Consortium globally are just a few of the projects that have contributed to the continued development in institutional use of OERs in the biological sciences. From lesson plans and lab procedures to case studies and multimedia tutorials, these platforms provide a vast array of biological science resources that are routinely curated or peer-reviewed by expert organizations. To fit local curriculum, instructors can also modify or remix components of modular biology courses from sources such as OER Commons, Curriki, and Saylor Academy (Perryman & Coughlan, 2013; Hilton et al., 2014). Crucially, these OERs are now being modified to conform to competency-based and outcome-based educational frameworks, especially under accreditation regimes like the Washington Accord and the National Board of Accreditation (NBA), increasing their acceptability in formal educational systems (Yadav et al., 2022).

Open educational resources (OERs) bring many benefits, although there are limitations when applying them in the biological sciences. Among the challenges that educators regularly highlight are worries about the dependability and quality of some free resources, a scarcity of regionally relevant content, and insufficient training in digital pedagogy (Trotter, 2017; Baas et al., 2019). Among the quality assurance solutions being utilized to overcome these difficulties include collaborative grading models, metadata tagging, peer-review systems, and Creative Commons licenses (Pitt et al., 2020). Many universities and research organizations have also created faculty development programs and capacity-building initiatives to help teachers integrate OERs into their labs and classrooms. The convergence of OERs with **MOOCs, LMS platforms, AR/VR tools and digital libraries** further amplifies their utility in biological sciences by ensuring continuity of learning, especially in contexts such as pandemics or natural disasters that disrupt traditional educational systems (Zawacki-Richter *et al.,* 2020; Sharma *et al.,* 2021).

3. Importance of OERs in Entomology Education

In entomology education, Open Educational Resources (OERs) have become essential tools because they provide creative, affordable, and accessible ways to get beyond traditional pedagogical constraints when teaching difficult and highly visual subjects like insect morphology and taxonomy. Entomology, by its very nature, requires students to understand detailed anatomical structures, classification systems, ecological interactions, and species-level identification components that depend heavily on access to physical specimens, microscopes, identification keys and taxonomic literature (Gullan & Cranston, 2014; Triplehorn & Johnson, 2005). However, in many academic institutions, especially in low- and middle-income countries, access to curated insect collections, contemporary laboratory technology, and professional taxonomists is limited or totally lacking. In such contexts, OERs offer a transformative alternative by providing high-resolution images, interactive identification keys, virtual dissection modules, 3D models, and crowd-sourced databases that make entomological knowledge universally accessible and pedagogically effective (Blagoderov et al., 2012; Ziegler et al., 2021).

The visual richness and taxonomic specificity required in insect studies are well supported by OER platforms such as BugGuide.net, Morph bank, Lucid Central, iNaturalist and the Encyclopedia of Life (EOL), which provide thousands of openly licensed images, detailed species descriptions, and taxonomic metadata curated by both professionals and citizen scientists. These materials enable students to study morphological variances between orders and families, identify key diagnostic traits such as wing venation, antennae kinds, and mouthpart structures, and practice classification tasks using real-world examples (Marshall, 2017; Nugent & Lear, 2020). For instance, BugGuide.net offers as a sophisticated visual resource where learners may explore, search, and compare insect photographs sorted taxonomically and linked with expert comments. Similarly, Morph bank offers multiple specimen views that replicate the experience of examining pinned insects under a microscope (Blagoderov *et al.,* 2012).

Additionally, the usage of OERs promotes inclusive and flexible learning, especially in light of the increasing demand for remote and digital learning. For instance, many entomology departments experienced significant delays in field and lab-based training during the COVID-19 pandemic. OERs supported continuity by giving virtual lab modules, simulation-based insect dissections, and remote field guides, so reducing learning losses and improving student engagement (Sharma et al., 2021; Bowman et al., 2020). Even beyond crisis contexts, OERs support differentiated instruction for diverse learners, including those with visual or auditory impairments, by integrating text-to-speech features, scalable images, and multilingual content tools that are essential for promoting equity in science education (Baas et al., 2019; UNESCO, 2012). Moreover, platforms like iNaturalist promote experiential and inquiry-based learning by involving students in biodiversity documentation projects, thus reinforcing classroom knowledge through real-world applications and citizen science engagement (Sullivan *et al.,* 2014; Nugent & Lear, 2020).

In the Indian context, the National Agricultural Higher Education Project (NAHEP) and the Indian Council of Agricultural Research (ICAR) have prioritized the incorporation of digital pedagogy, including OERs, in undergraduate and postgraduate entomology curricula. These programs aim to build outcome-based education (OBE) models, where digital information such as animations of insect life cycles, movies on insect behavior, and virtual microscopes are used to satisfy specific learning outcomes (Yadav et al., 2022). Additionally, by allowing educators to access and modify internationally reviewed information without copyright constraints, OERs promote collaborative knowledge generation and distribution and assist educators' ongoing professional growth (Hilton, 2016; Pitt et al., 2020). The "5Rs framework" of OERs—retain, reuse, revise, remix, and redistribute—makes these resources pedagogically flexible, enabling educators to adapt content to local insect fauna and agro ecological conditions (Wiley, 2014; Hilton et al., 2014).

From an educational perspective, OERs have shown promise in strengthening fundamental entomology skills like vector biology, pest and pollinator taxonomy, ecological interaction analysis, and morphological identification. Interactive resources like Lucid Keys offer digital alternatives to traditional dichotomous keys, making identification more intuitive for beginners while keeping the scientific rigor needed for academic and applied uses (Walker, 2010). Furthermore, the combination of OERs with Learning Management Systems (LMS), MOOCs and Augmented Reality (AR)/Virtual Reality (VR) platforms has offered new options for immersive entomology education. By enabling students to investigate insect habitats, behavior, and microstructures in three-dimensional settings, virtual reality tools help close the knowledge gap between classroom education and practical experience (Ziegler et al., 2021; Bowman et al., 2020).

4. Global OER Platforms Relevant to Insect Morphology and Taxonomy

4.1 Bug Guide.net

Iowa State University created and maintains Bug Guide.net, a comprehensive, community-driven online resource that provides a platform for the identification, study, and documenting of North American insects, spiders, and related arthropods. It hosts thousands of high-resolution, user-submitted images arranged taxonomically and annotated by both professional entomologists and citizen scientists. Bug Guide is notably effective in entomology education for teaching insect morphology and taxonomy, as it allows users to observe morphological features, compare species within and across orders, and receive real-time identification assistance. It is an important Open Educational Resource (OER) that promotes both formal and informal learning because it is publicly available (Marshall, 2017; Bug Guide, 2024; Nugent & Lear, 2020). Bug Guide.net is an extensive database of North American insects maintained by Iowa State University Marshall, (2017). It provides:

- Photos with morphological tags.
- Family/order-based diagnostic characteristics.
- Taxonomic debates and identification aid.

4.2 Morph bank

Morph bank is a global, open-access biological image database that supports research and education by providing high-resolution images of morphological structures, particularly useful in taxonomy and systematic. Users can upload, comment, compare, and share photos of specimens, including several views (dorsal, lateral, and ventral) and developmental phases, using Morph Bank, which was first developed by Florida State University with funding from the National Science Foundation. In entomology education, it serves as a helpful OER by enabling students and instructors to examine insect morphology remotely, compare diagnostic features and engage with curated visual data for identification and classification activities (Blagoderov et al., 2012; Morph bank, 2024).Morph bank (biological imaging resource) delivers high-resolution photos supplied by scientists globally Blagoderov et al. (2012). It supports:

- Comparative morphology across life stages.
- Multiple views (dorsal, lateral, ventral).
- Metadata covering taxonomy and locale.

4.3 iNaturalist

iNaturalist is a widely used open-access platform that mixes citizen research, biodiversity informatics, and educational outreach, making it a viable Open Educational Resource (OER) for teaching entomology. It allows users including students, researchers, and nature enthusiasts to post images and observations of insects and other creatures, which are then identified through community input and AI-assisted recognition methods (Seltzer et al., 2019). The platform provides as a dynamic field-based learning environment where learners can engage in real-time insect identification, improve taxonomic skills, and contribute to global biodiversity databases. INaturalist's inclusion into entomology classes boosts experiential learning and enhances understanding of insect ecology, taxonomy, and distribution (Putman et al., 2021). Moreover, the database is linked to the Global Biodiversity Information Facility (GBIF), ensuring that validated observations contribute to scientific research and conservation planning (GBIF,2024).iNaturalist, a citizen science platform, has pedagogical implications through Nugent & Lear (2020):

- Photographic recordings that have species information attached to them.
- Crowd sourced identifications.
- Morphological differences and field-based identification.

4.4 Lucid Keys

Lucid Keys are interactive, web-based identification tools that give a user-friendly interface for identifying organisms particularly insects based on morphological attributes, and they are increasingly being accepted as Open Educational Resources (OERs) in entomology education. Unlike typical dichotomous keys, Lucid keys allow users to enter observable characters in any order, making the procedure more flexible and accessible for students and non-specialists (Smith & Fisher, 2009). They provide the integration of multimedia, such as distribution maps, movies, and high-resolution photos, which increases student engagement and improve diagnostic feature memory. Notable examples are the Lucid Key to Insect Orders developed by CSIRO and Lucid Keys for Australian Freshwater Macro invertebrates, which have been successfully integrated into academic curriculum and biodiversity assessment programs (CSIRO, 2024). By enabling inquiry-based learning and self-guided identification, Lucid keys serve a significant role in boosting taxonomy education and citizen scientific involvement (Dallwitz et al., 2000).Lucid offers interactive, multi-access identification keys for insect taxaWalker, K. (2010).

These comprise:

- Dichotomous and matrix-based keys.
- Embedded photos and glossary.
- Both offline and integrated with LMS systems.

5. Visual and Interactive OER Tools in Insect Morphology

5.1 High-Resolution Anatomical Atlases

High-Resolution Anatomical Atlases play a significant role in boosting the teaching and learning of insect morphology and taxonomy by offering detailed, zoom able images of anatomical structures at macro- and micro-scales. By providing thorough renderings of insect body parts like antennae, wings, mouthparts, and genitalia, these digital atlases allow students to study important diagnostic characteristics that are frequently challenging to see with conventional laboratory microscopy. For instance, the Insect Morphology Atlas from the Smithsonian Institution and the high-resolution photography available through Morph Bank and Ant Web serve as exemplary OERs that bridge the gap between static textbook illustrations and living specimens (Dikowet et., 2017; Blagoderov et al., 2012). These atlases promote asynchronous and remote learning, facilitate self-paced study, and are especially advantageous for visually led subjects like entomology. Additionally, they support education and systematic research by combining cross-sectional imaging, taxonomic annotations, and metadata (Johnson et al., 2013).Scalable vector graphics for insect body parts can be found in digital atlases such as the USDA's Insect Anatomy Atlas. These are the main topics covered in beginning entomology classes (USDA Insect Anatomy Atlas, 2020).

5.2 3D Insect Models

Insect 3D reconstructions are currently available on platforms like Sketchpad and BioDigital Human. These models can be rotated, dissected, and labeled interactively Ziegler and associates (2021).By offering interactive, manipulable, and incredibly detailed visuals, 3D insect models have become potent Open Educational Resources (OERs) that improve students' comprehension of intricate insect morphology. These models enable students to investigate small anatomical elements that are frequently challenging to study in preserved specimens or through 2D schematics, such as compound eyes, mouthparts, wing venation, and genitalia (Johnston et al., 2017). By providing rotation, magnification, and layer-by-layer study, 3D models imitate real-time dissections and morphological investigations, making them especially beneficial for distance learners and institutions with restricted access to physical entomological collections (Peach et al.,2021).Open-access 3D insect models made from micro-CT scans, photogrammetric, or 3D rendering software are hosted on platforms like Sketchpad, Morpho Source, and Bio Digital Human, supporting international initiatives in digital taxonomy and entomological education (Faulwetter et al., 2013; Wipfler et al., 2016). These resources help with outreach, biodiversity documentation, taxonomy training, and teaching.

6. Curriculum Integration of OERs in Entomology Courses

The way insect biology, morphology, taxonomy, and ecology are taught in both traditional and remote learning environments have undergone a radical change with the incorporation of Open Educational Resources (OERs) into entomology curricula. OERs provide dynamic, adaptable, and cost-effective teaching resources that encourage interactive and student-centered learning. Their incorporation into curriculum boosts accessibility to up-to-date content, including annotated bug photos, interactive keys, field guides, virtual dissections, simulation tools, and peer-reviewed open textbooks. Such tools are particularly beneficial in teaching complicated morphological structures and taxonomic keys, which generally need expensive laboratory infrastructure or physical specimen collections (Pomeroy et al., 2019; Santos et al., 2021). For instance, platforms like BugGuide.net, Morph bank and Lucid Keys have been effectively integrated into university-level entomology courses to assist hands-on identification exercises, digital lab work, and student-led research projects (Marshall, 2017; Deans et al., 2012).

Additionally, OERs make it possible to incorporate up-to-date, region-specific taxonomic data, giving educators the ability to localize lessons and discuss new scientific advancements. Furthermore, these materials allow active learning through visual and experiential information delivery, catering to varied learning styles and enhancing student interest in insect morphology and classification (Hilton, 2016; Bliss & Smith, 2017).OERs bridge the gap between theoretical understanding and practical application since many entomological concepts, such as wing venation, antennae kinds, or larval morphologies, are intrinsically visual. Modules, digital field manuals, blended learning systems like Moodle or Canvas, and Massive Open Online Courses (MOOCs) can all be used to integrate core and elective courses. In essence, incorporating OERs into the entomology curriculum not only democratizes access to excellent education but also corresponds with the ideals of modern pedagogy by fostering open science, collaborative learning, and worldwide academic collaboration (UNESCO, 2021; Wiley & Hilton, 2018).

Conclusion

The teaching of insect morphology and taxonomy has benefited greatly from the use of Open Educational Resources (OERs), which offer easily available, interactive, and pedagogically rich platforms that enhance student engagement and learning outcomes. These resources, which vary from professional tools like Lucid Keys, Morph bank, and 3D anatomical atlases to community-driven databases like iNaturalist and BugGuide.net, democratize knowledge, allow curriculum integration, and encourage practical learning outside of traditional classrooms. High-resolution photos, virtual labs, simulation tools, and multilingual content all support inclusive and flexible entomology instruction in a range of learning environments. The strategic use of OERs will be vital in strengthening taxonomic knowledge, fostering biodiversity literacy, and preparing the upcoming generation of entomologists for both research and practical concerns as digital pedagogy evolves.

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