Entomology Education Since 2000: Methods, Outcomes, Challenges, and Suggestions for Practice

By Elizabeth Woolner
Ecology and Evolutionary Biology, University of Colorado at Boulder

October 30, 2020

Thesis Advisor:
Dr. Lisa Corwin, Ecology and Evolutionary Biology

Defense Committee:
Dr. Lisa Corwin, Ecology and Evolutionary Biology
Dr. Pieter Johnson, Ecology and Evolutionary Biology
Dr. Andrea Feldman, Program for Writing and Rhetoric

Abstract

Insects are fundamental aspects of nearly every ecosystem on the planet, providing key ecosystem services like pollination, decomposition, and maintaining food webs, in addition to constituting around 50% of all known animal species. However, the conservation funding insects receive does not reflect their importance to our ecosystems – rather, it reflects the lack of value we place on these organisms. In the face of significant regional insect population declines, a major challenge that arises in insect conservation becomes the development of a new conservation psychology. Education is a remarkable tool for increasing understanding and changing public attitudes about environmental issues; therefore, identifying how we educate learners about insects and what we could improve is of utmost importance to modern insect conservation. This literature review aims to characterize 1) how entomological education has been conducted in the last 20 years in the West, 2) what the outcomes are of effective entomological education, and 3) what challenges exist to entomological education. A list of suggestions for both general entomological education and conservation-focused education have been produced for educators in accordance with these findings and existing literature.

Introduction

Insects are fundamental aspects of nearly every ecosystem on the planet, providing key ecosystem services (such as pollination and decomposition) and acting as a food resource for other animals (Crespo-Pérez et al., 2020; Jankielsohn, 2018). They represent several major evolutionary revolutions that can inform human engineering -- veined wings developed outside of the tetrapod model, water-retaining exoskeletons, and a staggering amount of group-specific adaptations to vision, digestion, external morphology, and more (Lurie-Luke, 2014). In a normative sense, insects predate even the earliest proto-mammals by over 150 million years and have proliferated nearly uninhibited on land since 480-400 MYA (Misof et al., 2014). They have intimately co-evolved with many species, including the earliest flowering plants, and formed many symbiotic relationships, cementing their importance to ecosystems. Finally, and most staggeringly, based on current biodiversity estimates, the most common animal on Earth is a beetle (~25% of all known animal species) (Hunt et al., 2007). Both the utilitarian valuation of insects and the normative valuation provide a framework for the importance of conserving insects should they face danger. Insects are an integral part of ecosystems. Yet, while the debate among entomologists is ongoing regarding the true nature of global insect declines (Simmons et al., 2019; Thomas et al., 2019), there is reasonable evidence for significant regional declines in insect populations, biomass, and biodiversity (Hallmann et al., 2017; Janzen & Hallwachs, 2019; Leather, 2018; Lister & Garcia, 2018; Sánchez-Bayo & Wyckhuys, 2019). This is especially concerning through the lens of paleobiology, in which similar insect declines have only been observed in the fossil record during the Permian Extinction, when ~90% of all life on Earth went extinct (Erwin, 1996). The taxa most impacted include Lepidoptera (moths and butterflies), Hymenoptera (wasps, bees, and ants), Coleoptera (specifically dung beetles), and aquatic taxa such as Odonata (dragonflies and damselflies), Plecoptera (stoneflies), Trichoptera (caddisflies) and Ephemeroptera (mayflies) (Sánchez-Bayo & Wyckhuys, 2019). These latter four groups constitute the majority of aquatic insects. Specialist species, though theorized to be more at risk, are not the only ones experiencing declines -- generalist insects are as well. Sánchez-Bayo and Wyckhuys (2019) identified four major drivers of insect loss, listed in order of importance: habitat loss/urbanization, pollution by pesticides and fertilizers, biological factors like introduced species, and climate change.

Despite these identified trends, the true scope and characteristics of these declines are unknown to researchers due to lack of available long-term data driven by lack of interest in insects and difficulty conducting appropriate longitudinal studies (Cardoso et al. 2011). Indeed, the historical lack of research in entomology is a large contributor to the current lack of clarity about insect declines, in a way that other declining organisms do not face (Simmons et al., 2019; Thomas et al., 2019). This lack of knowledge, combined with human dislike for insects, is a large contributor to a small amount of conservation funding allocated for insects and arthropods. Conservation funding dedicated to insect species is not proportional to their diversity – the number of insect species and their importance to ecosystems far outweigh the conservation dollars they receive annually (Cardoso et al., 2011). Developing a new conservation psychology surrounding insects, including multiple diverse valuations of the animals, is one of the great challenges of insect conservation in our era (Simaika & Samways, 2018). Generating appreciation and understanding of insects in current and future scientists, policymakers, and citizens is a clear way to defend one of the environment's greatest resources.

The interrelatedness of public interest, greater scientific knowledge, and public action is well-documented (Page & Shapiro, 1983). Scientific knowledge, effectively communicated, can spur public interest, which forces leaders to act, such as in the classic American example of Rachel Carlson's *Silent Spring* (1962). Most major environmental policy in the U.S. has been fundamentally driven by public opinion, including the Clean Air Act and Clean Water Act (Rinfret & Pautz, 2019), and renewable energy policies in Europe are similarly influenced (Anderson et al., 2017). As a value-driven field, conservation efforts made to preserve and protect insect species require a valuation of insects on the public's part.

Education is a fundamental facet of public interest, a tool for policy formation, and could be used as a tool to increase interest in insects. Educational initiatives like outdoor programs and field trips have been shown to potentially increase appreciation of nature and the chances that a student has a stated desire to protect the environment (Chawla, 1998; Chawla & Cushing, 2007; Cheng & Monroe, 2012; Wells & Lekies, 2006). However, to make these changes in attitudes, long-lasting, certain best practices should be followed (Dillon et al., 2006). This project identifies themes in the literature about entomological education with the hope of creating effective strategies that could potentially create stable change in people's understanding and attitudes about insects. This project seeks to characterize current reports of how we educate K-16 students about insects in order to characterize recommendations to support a new entomological education philosophy that promotes insect conservation -- attempting to prevent the potentially catastrophic loss of insect species.

Methods

This research uses a systematic literature review to characterize multiple facets of entomology education through a thorough evaluation of current knowledge and practice in K-16 education. Analyses of peer-reviewed lesson plans and research articles were completed in order to evaluate the full scope of information available regarding entomology education. Both analyses take their systematic methodological basis from Rowland et al. (2019). This structure included defining research objectives, establishing inclusion criteria, using exclusion criteria to limit results, and ensuring the reliability of criteria. The systematic approach was used in order to more accurately assess the scope of the available literature and reduce the potential for researcher biases to impact the findings. It was also done to make the review more replicable, streamlined, and accessible to those not already immersed within the field.

Using Web of Science and ERIC, materials were searched using keywords (Appendix 2). When a search produced under 300 results, the abstracts of all results were read to determine whether they were appropriate for the study (Appendix 1). After abstracts were read, papers and lessons were read through in their entirety to more closely ascertain whether they fit the inclusion and exclusion criteria. If a search produced more than 300 results, more relevant keywords were added to reduce the result number. One round of snowball sampling using the bibliographies of selected papers was also completed.

Research Objectives

My aims were to:

1) Characterize how formal entomology education has been conducted in the last twenty years in a Western context.
2) Gather and synthesize reported outcomes from entomology education.
3) Gather and synthesize challenges to formal entomology education.

Inclusion Criteria

The inclusion criteria used by this literature review include 1) search keywords, 2) targeted goals of the study/lesson plan, and 3) year and location of the study/lesson plan. Keywords used (listed in their entirety in Appendix 2), included combinations of “entomology”, “education”, “insect”, “student”, “learning”, “teaching”, and more. Both studies and lesson plans must have been peer-reviewed to be included in the review, which was verified by ERIC and Web of Science. For ease of reviewing searches with many results, papers or lesson plans must have included the following terms in their abstract: “insect”, “arthropod”, “entomology”, a variety of insect/arthropod, and/or equipment or methods associated with entomology. Additionally, topics that are closely associated with entomology, such as biological controls or aggregations, were also included if they were related to insects within the study or lesson plan.

For the year published and location of the study/lesson plan, this review only included materials that were published after January 1st, 2000 and within a Western context. In this study, “Western Context” includes 1) NATO member states, 2) EU member states, and 3) Australia/New Zealand due to shared cultural backgrounds and similar values towards insects (Lockwood, 2013). Studies and lessons published during or after 2000 were chosen due to the increase in biotechnology knowledge and simultaneous decrease in natural history education observed during this time period (Tewksbury et al., 2014), trends that may impact modern entomological education.

The inclusion criteria for published studies and lesson plans vary only slightly, and both share the same criteria mentioned above. However, the final list of published studies was allowed to include examinations of learning materials or teacher integration of entomology (not simply studies about individual activities). Studies also had to report some level of evidence, including anecdotal, while lesson plans did not have this requirement.

Exclusion Criteria

The exclusion criteria for this literature review act as filters to ensure that the produced studies and lesson plans are relevant to the research objectives. These include 1) date, location, and type of study/lesson plan and 2) conceptual criteria.

As described above, if papers/lesson plans were published before January 1st, 2000, or were completed outside of the listed “Western context” countries, they were excluded from the analysis. Presentations, conference proceedings, or white papers were not included, as well as sources that were not peer-reviewed. Information about informal entomology education, such as external citizen science events, museum visits, etc., were not included as this review focused on formal educational methods.

The main conceptual exclusion criteria used by this study was regarding the research questions or learning objectives of the studies and lesson plans. For published literature, if the research objectives of the study were not useful for understanding and/or characterizing the methods, outcomes, and challenges of entomological education, the study was not included. For instance, a study attempting to measure student group cohesion and success via an insect-related activity would be excluded, but a study examining students’ attitude changes about insects via the same activity would be included. Similarly, for lesson plans, the lesson must have instructed about insects in a way that could promote understanding or appreciation, even when other learning objectives were present. For example, a lesson using aquatic insects to instruct about watershed health, in which students do not gain significant knowledge about the aquatic insects themselves but instead are focused nearly entirely on the ecosystem as a whole, would not be included. This exclusion criteria was designed to filter out studies and lesson plans that use insects in the periphery, rather than as a significant focus of the learning or research.

Another important exclusion criterion was that of spiders - papers or lesson plans that focused on spiders were not included. Evidence suggests that people respond to spiders differently than they do other arthropods -- their reactions being generally more negative -- and arachnophobia is one of the most common animal phobias (Gerdes et al., 2009; Jacobi et al., 2004; Lockwood, 2013). Therefore, when seeking to understand and characterize entomological education, information about spider education may confuse the results, and accordingly these papers/lesson plans were not included.

Ensuring Reliability of Measures

To ensure the reliability of the inclusion and exclusion criteria, our team evaluated these criteria systematically. For this analysis, “our team” refers to myself, Dr. Lisa Corwin, and Nicole Chlebek, a volunteer research assistant associated with the Corwin Lab. After my initial search for papers and refining criteria, a small sample of articles was given to Corwin and Chlebek who used the evaluative criteria to determine whether an article should be included. This list included articles that I determined should be included, were unclear, or should not be included in the study. The alternative readers’ ratings were compared with mine to determine agreement. For both Analysis 1 and Analysis 2, there was agreement among the three readers about the purpose and execution of criteria. Lesson Plan Criteria garnered an initial 77.6% agreement rate and Article criteria garnered an initial 87.3% agreement rate. Minor disagreements or misunderstandings were quickly assessed and feedback was integrated into the new criteria list.

Quantification of Characteristics

When the final list of papers were read, certain traits were quantified in order to see trends more clearly. The following two tables list 1) what traits were quantified while reading lesson plans, and 2) what traits were quantified while reading published articles. The traits were not of the articles themselves, but of the activities or phenomenon that were studied within the articles.

Term	**Definition**
Elementary	Pre-K to Grade 5 (or equivalent in non-American institutions)
Secondary through Collegiate	Grades 6-16 (or equivalent in non-American institutions)
Creativity-Focused	Lessons that had design or artistic elements as a key feature.
Easy Implementation	The lesson could be easily transplanted to a different classroom without excessive use of resources.
Used Technology	Lessons that included technology as a major feature (ex. Students perform all research via online sources, or view a video).
Live Insects	Lessons that utilize living insects/arthropods either as something to observe or in a more hands-on approach.
Perform Experiment	Lessons in which students executed a planned experiment (not just observation) or designed their own.

Table 1: Quantified characteristics of lesson plans.

Term	**Definition**
Elementary	Pre-K to Grade 5 (or equivalent in non-American institutions)
Secondary	Grades 6-12 (or equivalent in non-American institutions)
Collegiate/Instructors	Undergraduate education along with teacher professional development or surveys. These categories were merged because some studies on

	teacher attitudes use pre-service teachers, who are receiving post-secondary education.
In-Person Activities	The implementation of activities regarding the primary research question(s) of the study were held within a school or similar in-person environment.
Virtual Education	The primary research question(s) of the study revolved around the efficacy of various virtual methods.
Live Insects	Activities using live insects were included, even if not a specific research objective.
Learning Materials or Structures	Studies that analyzed educational implements that are more related to the context of learning, such as textbook content or teacher opinion, than individual activities.

Table 2: Quantified characteristics of published articles.

Results

Each search produced an average of 276 results on the ERIC search engine, and 72 results on Web of Science per search (Appendix 2). Many of these results overlapped when keywords were changed. Of these results, around 20% total were deemed relevant to the analysis of articles and around 50% were relevant to the analysis of lesson plans. These papers were given further attention and were then narrowed down using previously specified inclusion and exclusion criteria.

In total, 64 individual lesson plans and 21 published articles were analyzed and their characteristics recorded. Most lesson plans did not report outcomes, and those that did were anecdotal only. The bias of publication also indicates that these reported outcomes are more likely to be positive. These lesson plans therefore described best how entomological education has been done, rather than identifying outcomes. The studies, however, analyzed the outcomes of educational interventions in a more objective manner. Both were used to identify challenges to entomology education.

For reference, both published articles and lesson plans have been numbered (Appendix 1). To distinguish between them in in-text references, published articles will be prefaced with a "PA" and lesson plans with an "LA".

Analysis of Lesson Plans - How has formal entomology education been done?

Summary of Lesson Plan Characteristics

Age	**Common Lesson Plan Characteristics**				
	Creativity-Focused	**Easy or Flexible Implementation**	**Uses Technology**	**Uses Live Insects**	**Perform Experiment**
Elementary (69% of total)	17 (36%)	23 (52%)	8 (18%)	25 (56%)	12 (27%)
Sec/College (27% of total)	3 (17%)	5 (29%)	5 (29%)	13 (76%)	15 (88%)

Table 3: A report on the characteristics of 61 lesson plans. Three were excluded as they were not written for a specific age range.

Five common themes emerged as topics in these entomology lessons. They include:

1) *Process of Science* (48% of lessons)

Whether students were engaging in experimentation, design, or observation, many lesson plans focused on exposing students to the process and thinking behind scientific inquiry. Others even had students act as entomologists and think like a "bug scientist". While students of all ages and levels were given these lessons, the specificity and detail of scientific thought increased when older students were involved. In the Ingram and Golick (2018) survey, 72% of secondary teachers reported integrating scientific practice into lessons about insects, supporting this finding within the lesson plans.

2) *Ecosystem Dynamics* (42% of lessons)

Insects are frequently used to demonstrate ecosystem dynamics due to their importance to ecosystems and complex interactions with other organisms. Students of all ages participated in activities about insects and their ecosystems. This finding is supported by Ingram and Golick (2018), in which 92% of secondary teachers indicated that they used insects to instruct about ecosystem functioning, and 72% for ecosystem indicators. This also included insect behaviors with a direct impact on ecosystems (ex. pollination).

3) *Insect Anatomy, Behavior, and Ecology* (39% of lessons)

This category included ecological concepts such as life cycles, communication, or behaviors specific to a particular species. While these concepts inevitably have an impact on ecosystems, in these lessons insects were not used to demonstrate wider ecosystem functioning but were focused on more individually.

4) *Insect Interactions with Humans* (16% of lessons)

Like ecosystem dynamics, this category included a wide variety of lesson topics, such as forensic entomology, pest management, biocontrols, the process of entomology, and dilemmas caused by insects. Students learned to both navigate human-insect conflict as well as learned about the scientific value of insects.

5) *Effect of the Environment on Organisms* (14% of lessons)

The effects studied include changes in behavior or anatomy based on a variety of environmental factors (humidity, light, nutrition, etc.). This theme was usually executed through inquiry, and, based on the increased complexity of the experiments, secondary and collegiate students were the typical recipients of these lessons. Insects were convenient to use for these experiments as they are easier to handle and observe changes than other organisms.

Similarly, five common instructional methods emerged from the 64 lessons:

1) *Inquiry - Observation* (52% of lessons)

Inquiry-based approaches to science education involve students participating in interactive activities meant to simulate scientific processes and stimulate curiosity about natural phenomenon (Pedaste et al., 2015). This style of investigative learning can involve observation of phenomenon or empirical testing, described below. Many of the entomological lessons utilized observation to give students agency over their scientific learning and guide inquiry. Most occurred outdoors or using live insects, but some made use of plastic insects or other models to achieve the same goal. Students were often tasked with keeping a notebook of their findings and coming to conclusions based on evidence.

2) *Inquiry - Experimentation* (38% of lessons)

Using another type of inquiry-based approach, entomology lesson plans frequently used experimentation activities to guide learning. This is defined by students carrying out empirical testing of their (or an instructor's) design or following the scientific process of inquiry to come to conclusions about insect biology, typically through active manipulation of variables. Unsurprisingly, the complexity of experimentation increased with the age of students, and completing the full scientific process (from conception to conclusions) became more common with older students.

3) *Modeling* (20% of lessons)

Modeling, the process of constructing representations and visualizations of a phenomena for the purposes of increasing understanding (Louca & Zacharia, 2012) was used frequently in the entomology lessons in several forms. Students drew pictures, made diagrams, created 3-D works of scientific art, and designed insect habitats / traps / enclosures, among other items. These are grouped as modeling as they are all attempting to conceptualize phenomena or design implements to interact with the natural world.

4) *Drama / Theatre* (19% of lessons)

Perhaps an unexpected finding for science education, in multiple lessons students were encouraged to take on an alternate persona to investigate some aspect of insect biology. This persona was sometimes entomologists, and other times insects themselves. Students then immersively acted as these roles to achieve learning objectives.

5) *5E Learning Cycle* (13% of lessons)

The 5E learning cycle (Duran & Duran, 2004), consists of Engage, Explore, Explain, Elaborate, and Evidence steps of learning. It is a commonly utilized framework for designing inquiry-based lessons, and often lists learning objectives at each step of the process. However, while many 5E-based lessons have an inquiry component, not every inquiry lesson follows the 5E cycle, and certainly not explicitly. When included, this framework was used to design the lessons and provide structure.

Summary of Findings from Lesson Plans

The methods and scope of entomology education varied with age. The majority of lesson plans (69%) were written for elementary-aged students, and these lessons were more likely to be easy to implement, creativity or design focused, and handle insects outside of an experimentation context. In contrast, only 27% of the studied lesson plans were written for secondary or collegiate students, and nearly 9 of every 10 of these were inquiry-based experiments. If students handled live insects, it was nearly always in the context of these inquiries, and very few lessons were focused on the creativity of the older students. This indicates a significant difference in the way older and younger students are taught about entomology. Older students are more likely to use insects as tools, often for inquiry about physiology or the natural world. Younger students, on the other hand, are exposed to lessons that are generally more “fun”, creative, or exploratory.

As observed in the emergent themes, while insect biology played a critical role in each lesson, it was less common for a lesson plan to solely focus on insects. A typical learning objective followed the format of: *Students learn about <u>[specific aspect(s) of insect biology]</u> to apply it to larger concept(s) <u>[ecosystem dynamics, process of science, etc.]</u>*. While this indicates insects’ efficacy as a vessel for instruction on other topics, it also may reflect a hesitancy to teach about insect biology specifically, without another learning objective attached. It also may indicate a more anthropocentric viewpoint guiding the design of the lessons.

As far as study organisms, the majority of lessons utilized more charismatic arthropods, including butterflies, bees, pillbugs/woodlice/rolly-pollies, ants, or beetles. Those who did not use a typically charismatic organism often made a sincere case for why their organisms actually were charismatic or how their usefulness outweighed other factors -- eg. the Madagascar Hissing Cockroach or mealworms. This approach has both positives and negatives. While charismatic animals are less likely to elicit disgust or fear responses from students, allowing them to complete the lessons without stress, charismatic species do not accurately represent the breadth of insect diversity. Furthermore, while some insects (such as bees) provide vital ecosystem services, others (such as butterflies) are less critical for ecosystem functioning. Emphasized use of these species may impart inaccurate ideas on students about charismatic species' importance within ecosystems and the nature of insect diversity. Similarly, a focus on charismatic species takes an anthropocentric approach, rather than a nature- or biocentric approach.

Somewhat surprisingly, the tone used to write the lesson plans was nearly always positive regarding insects, even when students learned about human-insect conflict. Students were often encouraged to think from the insect's perspective to conceptualize their place in the environment, and then apply that line of thought to solving a problem as a human.

Analysis of Published Studies - What are the outcomes of entomology education?

Description of Studied Articles

Age Category	**Learning Type**			
	Virtual Education	**In-Person Activities**	**Live Insects**	**Learning Materials or Structures**
Elementary	0	8	6	0
Secondary	2	9	6	2
Collegiate / Instructors	3	3	3	1

Table 4: Age categories taught and learning type used within 20 peer-reviewed studies. One study was not included in the table as it did not fit a specific age category.

Outcomes

Outcomes of entomological education examined by these students included measures of attitude, motivation/interest, behaviors, content (insect) knowledge, and transfer tasks. Attitude, as generally defined by the reviewed articles, is largely centered around the emotions students have regarding insects. These were sometimes derived from Biophilia framework (Kellert 1993), and included both “insect-positive” and “insect-negative” emotions such as fascination, appreciation or joy, and disgust or fear. Motivation and interest measures focused on intrinsic motivation, student engagement, and enjoyment with the lesson or topic. Future and current motivation were studied. Furthermore, many studies separated attitudes and motivation from behaviors, which were measured as actions taken during or after the activity or stated intent to take action. In most cases, insect content knowledge was measured via correct answers to assessments, though these assessments could range from multiple choice, free response, or anecdotal discussions with students. To measure the transfer of knowledge, students were asked to reapply what they had learned in a new context and then were scored during an assessment.

Experimental groups are defined as those participating in a novel entomological activity or program, or given additional entomology content when their peers were not. While several studies investigating attitude and/or motivation did not provide clear definitions, a broad description can be produced. In nearly every study that examined entomological activities, experimental groups were significantly impacted by the educational intervention compared to the control groups. This includes measures such as post-test attitude scores, knowledge scores, transfer tasks, interest/motivation measures, and reported behaviors (PA 2, 3, 4, 5, 8, 10, 11, 13, 15, 15, 16, 17, 18, 19, 20). Certain populations benefited more from entomological education initiatives than others. Particularly, students from underrepresented groups, at-risk students, and students from urban areas were impacted positively by outreach (PA 3, 14, 18, 19). In Cornelisse & Sagasta (2018), urban students made significant gains in content knowledge, attitudes, and behavioral change compared to their peers when given both a conservation-based lesson and a basic insect biology lesson. In other studies, female students reported larger gains in similar measures when exposed to entomological concepts opposed to their male peers (PA 4, 15, 16).

On the other side of the educational equation, pre-service instructors also benefited from in-depth educational programs intended to increase their comfort with using insects in the classroom. Teachers trained in insect programs had an increased likelihood of incorporating specific learned insect species in curricula, a greater understanding of scientific concepts, and increased respect for student's ideas (PA 8, 19). Teacher education has the potential to have a major effect on positive insect interactions - if a teacher is comfortable integrating insects into their classroom, multiple years of students can be impacted by entomology-based lessons.

Teaching Modality

Instruction using live insects or in-person experiences is a commonly suggested practice in entomological education (Klingenberg, 2014; Randler et al., 2012; Wilde et al., 2012), and articles' research questions often focused on this modality of teaching (62% of papers). Unsurprisingly, when using these kinds of approaches, most studies found significant, typically "insect-positive" or "knowledge-positive" gains in the measured outcomes, as noted previously, and many studies endorsed the use of hands-on, in-person activities that use live insects as a unique way of teaching science.

However, one of the most surprising findings of this review was the effectiveness of virtual learning in entomology education. Several studies examined aspects of virtual learning, such as distance education, viewing of educational videos, using web resources to identify insects, and virtual tours (PA 1, 7, 12, 16, 17, 21). While shortcomings were identified -- particularly the potential for academic dishonesty and loss of hands-on science practice -- most reported that the virtual instruction was nearly as effective as traditional instruction or working with live animals, both in terms of content knowledge and affective outcomes (PA 1, 7, 12, 17). Others argued that entomology education must adapt with changing technological circumstances to better prepare students for future work (PA 21). These findings suggest that virtual learning may act as a substitute when traditional instruction or live animals are unavailable, and can be as effective as live instruction when paired with related activities.

Educational Approaches

A variety of different educational approaches were investigated by the reviewed studies. The following includes a list of such approaches and the corresponding Article ID:

Type of Activity	**Definition**	**Article ID**
Citizen science initiatives	Projects that students or other non-scientists can help collect data in order to achieve a larger scientific goal (U.S. GSA, 2020)	18
Classroom-based activities	Interactive activities based inside a classroom environment	2, 4, 8, 11, 13, 15, 16, 19, 20
Conservation-based learning	Learning based around conservation as a topic and practice	3, 20
Garden-based learning	Learning that takes place in and is centered around a local or school garden (Fisher-Maltese & Zimmerman, 2015)	5
Live insects	Activities that expose students to live insects	2, 4, 5, 8, 10, 12, 15, 16, 17, 18, 19, 20
Outside-of-classroom activities	Interactive activities based within a school or other formal learning environment, but take place outside the classroom	10, 11, 17
Service learning	Learning in which students reflect and directly apply knowledge to help communities (Eyler & Giles, 1999)	14
Traditional learning	Learning in a classroom in which the	6, 9

	teacher lectures to the class and/or utilizes textbooks as the main learning resource	
Virtual/Distance learning	Learning that either utilizes virtual opportunities as main features of the lesson (ex. Videos, programs, etc.) and/or learning completed at a distance through virtual means	1, 7, 12, 15, 17, 21

Table 5: Selected methodologies of studied activities, their definitions, and the corresponding articles that studied them.

Beyond the results described above, a few findings are worth highlighting regarding general teaching methodology. Firstly, hands-on activities were at greatest effectiveness when students were highly motivated, such as at the beginning of a lesson (PA 16), and/or when paired with other learning strategies, such as videos (PA 17). Getting scientists involved is a well-known tactic in science education, but this study pool's results questioned the effectiveness of such a strategy. While some papers suggested its importance or potential (PA 3), Weeks and Osteo (2018) found that it may lessen students' positive outcomes as scientists may not know how to effectively instruct young grades. Since many secondary science teachers report a desire to integrate more professionals into their classrooms (Ingram & Golick, 2018), these mixed findings deserve attention. Similarly, time proved to be a complex variable when studying the effectiveness of a strategy. Some activities' efficacy peaked at a certain point, such as around four weeks (PA 16), though there is evidence that short term programs can still produce attitude changes (PA 3, 15, 16, 17, 20). Longitudinal research in this area is few and far between. Rather than uncertainty, instructors may view this as flexibility for their individual situation - there is not a prescribed length of time required, and therefore they can adapt an activity to their needs. Finally, approaches that connected insect biology to the lives of students produced greater changes in attitude, motivation, and content knowledge (PA 2, 3, 5, 10, 13, 14, 18). This may be due to greater buy-in by students that are able to connect to the material.

Analysis of Lesson Plans and Published Studies - What are the challenges to entomology education?

Despite seeing the benefit of integrating insects into the classroom, teachers perceive that entomology education does not easily align with standards or prescribed curriculum (PA 9). However, what Analysis 1 has revealed is that nearly all of the published lessons available to teachers regarding entomology do align with overarching standards such as NGSS. Due to insects' universal nature, they can be integrated into other concepts or units such as ecology, scientific processes, or human interactions with the environment. While this does not account for prescribed curriculum set by states, districts, or schools, this finding stands in contrast to teacher's perceptions, and questions what may be the true challenges to entomological education.

Teachers themselves may also be a barrier to introducing insects into the classroom. Many report confidence in handling live insects or instructing with them, but also cite a lack of adequate professional development opportunities to improve their instruction (PA 9). There is also evidence to suggest that, while such programs improve teachers' likelihood of incorporating insects into the classroom, they may only feel comfortable with one species (9, 19) and will not expand to using other insects as models.

Other common concerns mentioned by instructors include lack of time, resources, and quality lesson plans (PA 9, 14). These concerns are also supported by findings from lesson plans, which reveal less explicitly the challenges to entomological education. Interactive lesson plans are difficult to implement for a variety of reasons. Many require long time frames (weeks to months) which are difficult to sustain for a low-resource or time-stressed classroom (e.g. LP 17, 23, 33, 44, 50, 63). Similarly, they may also conflict with standardized testing requirements. Obtaining and caring for live insects requires a set of resources as well -- to feed, house, and dispose of the animals ethically -- that simply may not exist for some teachers, despite proponents of these activities offering suggestions (e.g. LP 35, 43, 58, 63). Many observation activities require access to the outdoors or small natural spaces. For urban schools or those that lack gardens or transportation, these inquiry activities are difficult if not impossible. Furthermore, although virtual activities may provide similar levels of success to live ones, as revealed by schools' adaptation to COVID-19, virtual learning is also a contentious issue in terms of access. Students and schools may not have the resources, such as computers, fast wifi, and required software, to participate in quality virtual activities (Light, 2001). Finally, while experimentation is a common method to teach about insects, students and teachers may not have room for experiment "failure" if they have time, grade, or resource pressure. It is difficult to justify accessing limited resources for an experiment, especially if there is a significant chance that students will not produce a positive result (Gin et al., 2018).

Finally, materials used for entomology education inadequately describe the true diversity of insects and are decreasing in prevalence over time. In an analysis of textbooks and other related materials, Gangwani and Landin (2018) not only discovered a 75% decrease in insect related content since 2000, but also the language surrounding insects was generally becoming more polarized, with emphasis on the negative aspects of insects. This contrasts with tailored lesson plans, which have a tendency to use more positive language. Furthermore, certain taxa, such as grasshoppers, flies, and bees, were highly overrepresented compared to their actual diversity, inadequately representing insects overall. These changes indicate an additional challenge to entomological education -- lack of quality learning materials separate from lesson plans. As science classes become more textbook-focused, this challenge may intensify.

Discussion

From the results of the lesson plan and published article analyses, seven main themes were identified, and are described below.

Statement A: Lack of resources is the most important challenge to entomological education.

While other challenges were identified by teachers and via synthesis, such as lack of orientation with standardized testing, ultimately the most critical challenge to teaching about insects is a lack of resources (Ingram & Golick, 2018). This includes lack of training or professional development for teachers, lack of time, lack of monetary resources, and general support for these activities. The combination of these challenges result in classrooms where teachers are uncomfortable working with insects, do not have the time to sustain long-term, interactive activities, and/or cannot afford the tools that would make interactive lessons possible, such as live insects or virtual programs (PA 9). This may increase reliance on textbooks for information about entomology, especially in higher grades. Unfortunately, the information about insects in introductory biology textbooks is decreasing and the language surrounding them is becoming more neutral over time (PA 6). They also feature wildly inaccurate proportions of insect diversity, which can create misunderstandings about insects and ecosystems (Gangwani & Landin, 2018; Kuiper, 1994). Therefore, while they may be supported by administration and readily available to instructors, textbooks may not be the most effective resource in instructing about entomology in an engaging and accurate fashion and should not be relied on. Increasing resources for interactive activities should be the focus for interested administrators and researchers.

Statement B: Multiple methods and modalities of education can be used to instruct about entomology.

As demonstrated by the analysis of peer-reviewed articles, there are many available teaching methodologies and modalities that can suit entomological education. Approaches such as citizen science, service learning, garden-based learning, distance learning, experimentation and inquiry-based learning, and traditional classroom learning were all found to be effective in transmitting learning objectives. Although resources remain an issue, the ways insect biology can be taught is limited only to an instructors' imagination and can fit within the structure of multiple styles of instruction.

Similarly, both in-person learning and virtual learning were found to be effective, especially when virtual learning was paired with multiple activities (e.g. PA 1, 7, 12, 17). This is an especially relevant result given the changing relationship that instructors have with remote learning due to COVID-19. However, both modalities have a major drawback -- resources. While it is clear how in-person activities (especially with live insects) require a certain amount of time, training, and money, virtual activities also require available devices, high-speed internet, and a level of student/teacher comfort with using virtual tools. While some studies have touted virtual education as an effective, lower-resource alternative to live instruction (PA 1, 17), which may well be true for certain schools or classrooms, the issue of resources does arise. If a classroom cannot afford to raise insects, will they have enough computers for each student to effectively engage in a remote activity? Despite this challenge, the finding that virtual modalities can be effective for entomological learning is still an important one, as it provides instructors more tools to adapt to their individual situations. The tensions between these ideas pull in multiple directions - a desire for real, live experiences with insects conflicts with the potential benefits of virtual programming, and both are greatly impacted by a presence or lack of resources.

Statement C: Entomological education generally produces positive results, especially for certain groups.

When exposed to interactive entomology lessons, students generally experienced positive changes to their attitude, motivation, and behaviors regarding insects, the environment, and science (PA 2, 3, 4, 5, 8, 10, 11, 13, 15, 15, 16, 17, 18, 19, 20). They also performed better than their peers in academic measures regarding insects, implying that these activities are also effective in the delivery of content. Given the natural diversity of insects and their resulting potential to connect to many different fields or activities, this is an encouraging result to increase the use of insects in the classroom.

In a more specific sense, individual groups of students also received unique benefits compared to their peers. Urban students gained knowledge from both conservation and basic insect biology lessons while their suburban peers only made significant gains from the basic lessons. As urban students generally have less exposure to natural settings by nature of living in cities, entomology education may be an effective way to provide them with experiences interacting with nature. As insects are relatively convenient to keep and investigate within a classroom and are present in urban environments, location-, justice-, and student-centered activities about insects may alleviate some of the challenges associated with urban science education along with increasing environmental and insect appreciation (Schindel Dimick, 2016). Three studies also suggested methods for providing underrepresented or at-risk students with more entomological opportunities (PA 3, 14, 18).

This review has demonstrated that female students can show greater attitude change than their male peers, despite beginning lessons with a generally more negative view of insects. As female students generally have a greater dislike of insects and higher disgust sensitivity (Bjerke et al., 2003; Curtis et al., 2004; Prokop et al., 2011; Prokop & Fančovičová, 2010), this interactive exposure to insects may be vital to mitigating some of the challenges female students have when approaching entomology. Interestingly, despite representing the majority in biology and constituting around 50% of recently-granted entomology degrees, women are underrepresented in entomological positions in academia and government (Walker, 2018). Whether an increased focus on female students can counteract this career-related finding is debatable (since this pattern is likely formed from factors following a K-16 experience) but it may well improve attitudes about insects in the general female population, which would be an accomplishment in itself.

Given these benefits to underrepresented groups, there is potential within entomological education for community and social justice based science learning. Community or locally based projects simultaneously increase student buy-in and ownership over the project in addition to cultivating a positive attitude towards conservation (Ernst & Monroe, 2004; Battersby, 1999; Webster, 2006; Zylstra et al., 2014). Similarly, insects can live in environments where other species cannot, such as urban centers, and compared to many other organisms they are cheap to raise and keep in the classroom (LP 63). Activities that connect students to their community and provide them opportunities to practice science and natural history that they might not otherwise have could be potentially transforming experiences for at-risk, urban, or underrepresented students.

Statement D: PreK-5 and 6-16 students are educated differently in entomological education.

The differences between the education of older and younger students in entomology takes a few forms. Firstly, there are far more activities written and published for elementary students than secondary. This indicates that entomological education may decrease as students age, or that there is a publication bias favoring elementary-aged activities. The activities that were published for older students were nearly always inquiry-based, and often experimental (e.g., LP 1, 24, 40, 44, 63), in which students were manipulating conditions to produce changes in insect behavior. They are also exposed to increasingly neutral and distanced language surrounding insects via their classroom textbooks (PA 6). Younger students, on the other hand, more frequently engaged in observational, creative, or visual modeling activities (e.g., LP 2, 7, 18, 32, 53). Through these lessons, they are more likely to form emotional or creative connections with insects, and their activities are more likely to have dual focus on skills and entomological content (e.g. LP 14, 16, 21, 31, 43). These findings reveal assumptions made within science education about different ages of students. There is a perception that younger students are more likely to respond positively to potentially disgusting animals, and that environmental attitudes are most flexible before the age of 12 (Caduto, 1983; Jaus, 1984; Kellert, 1985). Therefore, focusing entomological education on younger students may attempt to seed attitudes and behaviors about insects before they become inflexible. In addition, as a result of an inquiry-heavy approach, older students may learn to see insects as merely tools to aid in scientific or ecological inquiry, and the personal connections to insects, even if formed in earlier years, may be lost. These personal connections are critical to changing attitudes and behaviors around insects, as well as encouraging motivation for future study (Hidi & Renninger, 2006). While the assumptions made about the pre-existing attitudes about younger and older students may be supported with evidence, it may also be necessary to maintain some of the strategies generally used with younger students throughout secondary entomological education.

Lastly, and interestingly, none of the 21 studies investigated the impact of virtual learning on elementary-aged students. Despite the increasing technological awareness of young children, in-person activities are likely favored more by elementary teachers, or at the very least studied more frequently. This creates a major gap in knowledge when young students are forced to learn remotely -- for example, due to COVID 19 -- and may create problems for teachers under such scenarios.

Statement E: What is taught in entomological education generally aligns with expert consensus on important topics.

Pearson et al. (2007) surveyed 236 entomologists who attended the Entomological Society of America’s national conference in 2004, garnering their answers to what they thought was important for all Americans to understand about insect biology. Synthesizing these responses and previous research, a list of potential core competencies in entomology was created (see supplementary materials), with the following five key concepts established:

1. Insects have environmental value
2. Insects have investigative value
3. Insects have economic value to humans
4. Insects shouldn’t be controlled without considering a balance of risks and benefits
5. Insects have aesthetic value

Fortunately, as observed with the Five Emergent Themes identified by this review, instructors are already teaching about topics that insect experts agree are critical for students to be educated on. Furthermore, these statements use positive evaluations of insects such as “value”, correlating with the typically positive language used by lesson plans. However, the most resounding idea for instructors to impart to students, according to the results of this survey, was *to understand how insects are valuable to humans*. This would increase motivation to learn about insects, leading to better outcomes for the other topics in the future (Pearson et al., 2007).

However, there is one key issue with basing the standards for entomological learning on Pearson -- it was published in 2007, and data was collected in 2004-5, well before insect declines appeared as a major issue. Some of the seminal studies in this area were published a decade or more after the publication of this paper (Hallmann et al., 2017; Janzen & Hallwachs, 2019; Lister & Garcia, 2018; Sánchez-Bayo & Wyckhuys, 2019). Therefore, the standards established by this research may not reflect current trends in entomological thought or what students need to know based on new information.

Statement F: From an educational perspective, there is tension between anthropocentric and biocentric approaches to learning.

A major tension revealed by this review arises between anthropocentric entomological education and biocentric, or nature centric, entomological education. This is possibly best conceptualized in the debate of whether to use charismatic species in insect learning. Should entomological programs use charismatic insects with the goal of getting students through the lesson and potentially improving attitudes towards all insects by proxy? Or is it a disservice to students and a disrespect to the natural world to underemphasize the true diversity of insect and arthropod life? What content or context about insects are being left out when charismatic species are the only animals chosen for close study? There are potential issues with not teaching the real diversity of insects accurately. For example, misconceptions and inaccuracies could be produced in students' knowledge, which frame all subsequent learning (Kuiper, 1994; Wenning, 2008). However, working with uncharismatic organisms has mixed results for appreciation of insects (PA 4, 19), and may increase negative attitudes and behaviors (PA 2). Balancing the need for student interest and appreciation with true insect biodiversity is critical for instructors or curriculum developers.

Tension between anthropocentric and biocentric views can also be seen in the different approaches to entomology education - one focusing on skill, and another focusing on content. Older students, for example, are more likely to learn about insects as tools for inquiry, and therefore hone their inquiry and experimental skills while doing an insect activity - this is more anthropocentric. Younger students, on the other hand, are more likely to learn about topics such as, "how do insects call one another?" or "what are the body parts of an insect?", which is more biocentric. Similarly, a hypothetical college entomology program has a choice - focus more on skills, such as pest management, or more on content, such as insects' value to ecosystems. While this is not a distinct binary, and lessons/programs can integrate both into their curriculum, it does raise the question of what the purpose of entomological education is. Skills are generally more anthropocentric and content is generally more biocentric. Similarly to the choice between charismatic versus uncharismatic species, these decisions can influence students. Skills-based lessons may teach students to understand insects only in a human-centered (scientific, agricultural, etc.) context, while content-focused lessons may generate appreciation for insects on their own, but neglect the intricate connections between insect and human life. Understanding and balancing this tension is likely an avenue for future entomological education.

Statement G: Within the existing framework of entomological education, there are opportunities to pursue conservation-focused learning.

To counteract lack of public attention on insect population declines, there may well be a need within entomological education to focus on conservation outcomes in entomological education. Fortunately, the field is already following some suggested practices for conservation learning. These include positive messaging, using conservation ambassadors, and combating extinction of experience (Simaika & Samways, 2018). Conservation psychology literature encourages the use of positive and action-focused language when educating about environmental issues, as it instills a sense of hope and agency in students to affect change (Schultz, 2011; Simaika & Samways, 2018; Weinstein et al., 2015). The language of the lesson plans already reflected this practice, with students being asked to sympathize with insects, understand their importance, and generate solutions to problems (e.g. LP 20, 21, 26, 55). This approach could be used to counter increasingly negative language that students may encounter in textbooks (Gangwani & Landin, 2018). Though it is a source of debate in insect conservation, in many other settings the use of conservation ambassadors - species that are charismatic and relatable, who's protection may influence many other species - has been proven to be effective. Even within insect conservation, the use of monarch butterflies and honeybees have generated large public conservation efforts (*Monarch Butterfly Fund*, 2020; *Xerces Society*, 2020; *The Honeybee Conservancy*, 2020; New, 2012; *Save The Bees*^{TM}, 2020). The lessons and activities reviewed commonly used charismatic species, or made a sincere case as to how they could become charismatic (E.g. LP 19, 27, 34, 50, 63). Reviewed studies that investigated the use of uncharismatic arthropods in educational efforts found that use of these species may not have produced as positive of outcomes as use of charismatic species. Therefore, the use of conservation ambassadors can easily be applied to entomological education. Finally, many scholars agree that one of the main goals of environmental education in developed countries should be tackling the “extinction of experience”. This term describes the lack of direct connection that modern generations have with nature as people in developed countries increasingly live in a technological world (Samways, 2007; Soga & Gaston, 2016). Based on this review, entomology education is combating this phenomenon by exposing students to live insects, participating in inquiry and observation activities, and focusing on the connections between human and insect life.

While insect and arthropod conservation is a pressing topic, there are drawbacks to integrating these concepts within entomological education itself. Ultimately, these approaches suggested by conservation psychology are anthropocentric. At what point do instructors focus so much on the human aspects of the human-insect relationship that insects are neglected within their own lessons? It may be more beneficial for some instructors to teach about insects with a more intrinsic valuation lens. Many entomologists anecdotally report fascination being a key factor in choosing their eventual career path (Pohl, 2009), and therefore, teaching about insects for insects’ own sake could increase this sense of wonder for some groups. Similarly, what is proven to work with other organisms may simply not work for insects - there is evidence to suggest that there is some instinctual human dislike for insects based on their role in disease or other threats (Curtis et al., 2004; Lockwood, 2013; Simaika & Samways, 2010). For some, insects may simply be too inhuman or vile to change their minds or behaviors for, and therefore, the fundamentals of effective conservation messaging may fail. Finally, conservation is a political topic, raising the question of whether entomology education (and, by extension, science education) should deal explicitly with political issues. A clear motive for the lesson, such as conserving insects, may meet resistance among instructors, administrators, parents, and students, even if the lesson provides opportunities for the students to express different viewpoints and identify alternative solutions.

Study Limitations

Several limitations exist to the current review. First and foremost, the sample size of our peer-reviewed articles was small, without much overlap between the effectiveness of different learning strategies. There is a significant data gap in entomological education regarding this. Furthermore, as far as the methodology of entomology education, we cannot speak to any lessons or strategies that remain unpublished. What many teachers actually execute in the classroom may be different from what lesson plans are available in the published literature. Similarly, some of the studies used in our review had significant limitations to their findings. For example, Ingram and Golick (2018) only surveyed self-selected secondary science teachers. This biases their findings towards instructors that are generally more comfortable with insects, and those that do not teach younger grades. It is likely that this bias is evident in other studies and lesson plans as well, since those authors publishing are more likely than the general public to be interested in or comfortable with insects. Similarly, only one longitudinal project was included in the study, but in its early stages. Throughout this review, we have attempted to be as clear as possible what groups are being referred to by these studies and which are not included.

Conclusions and Suggestions for Practice

Based on the findings of this study, the following practices are recommended for general entomological education:

1) *Get entomology into the classroom*

The underlying finding from this review is that integrating insects into the classroom has a series of positive benefits and is relatively easy to integrate with other science curriculum due to insects' natural diversity and importance to ecosystems. However, insect integration remains low. Therefore, the primary goal of entomology-interested educators and administrators should be getting entomology into the classroom, especially using interactive activities. This may be especially effective for older, urban, and female students as well as instructors themselves.

2) *If resources are available, experiment with different methods of instruction*

In this review, several methodologies and modalities of instruction were identified as effective in increasing content knowledge about insects and related topics, and improving attitudes, motivation, and behaviors of students around insects. Therefore, instructors are limited only by resources and their imagination in their integration of insects into the classroom. Some projects, such as citizen science or community projects, have the additional impact of influencing groups outside the classroom. That being said, resources to attempt these novel approaches are lacking, and their implementation requires some experimentation, risk, and collaboration on the part of instructors and administrators.

3) *Connect lessons to students' personal lives to increase motivation and buy-in*

Students, and people in general, respond best to scientific and conservation messaging when it connects to their personal lives or they can see a point to it. This review similarly found that entomological lessons that students could relate to appeared to generate more motivation and buy-in from students. Therefore, especially with a topic as alien as insects, it is crucial for instructors to relate educational activities to their students' experiences in order to increase learning and potentially change behaviors.

4) *Rely less on textbooks and more on published, interactive activities*

When possible, interactive activities should be favored to teach entomology more than textbooks, especially with older students. Textbooks are not adequately representing the biodiversity of insects or their intricate relationships with humans, whereas published, interactive activities are. While textbooks may be helpful for context, instructors should strongly prefer the use of hands-on activities when teaching about entomology specifically, to reduce misinformation and increase student buy-in.

For education with insect conservation in mind, the following are recommended practices. These are derived from both the results of this review and existing literature on conservation psychology and environmental education.

1) *Reduce "Extinction of Experience"*

To minimize the distance students are experiencing from nature, instructors can implement a variety of different interactive activities that provide students with environmental experiences. While typically these activities involve field trips, outdoor explorations, or working with live insects, it is possible that virtual activities can also help reduce extinction of experience. Take young people's engagement with the Pokémon franchise, for example - though the collected animals are not real, students have incredible categorical knowledge of their nature and ecology, even more than real animals in their area (Balmford, 2002). This implies that some virtual experiences may be as immersive as live ones. The core trait of these activities should be the direct experience of nature, including activities like knowledge gathering, categorization, observation, and more.

2) *Use conservation ambassadors*

Despite the debate and mixed evidence over using charismatic species in entomological education, there has been proven success in using likable species as the figureheads of conservation movements, especially in insect conservation (e.g. Monarch butterflies and honeybees). Instructors charged with the teaching of insect biology must balance the need for charismatic ambassadors with the true diversity of insects within their lesson planning.

3) *Focus on the Interconnectedness between Humans, Insects, and the Natural Environment*

Humans, insects, and the environment are intricately connected, and exploring these connections may both improve conservation attitudes (by realizing the extent to which humans depend on our environment) and preservation attitudes (by encouraging humility in the face of natural phenomenon). Instructors seeking to take a conservation focus in their entomology lessons should therefore emphasize, either through direct connections to students' personal lives or by exploring connections between organisms, the interrelatedness of insects, humans, and nature at large. Activities investigating ecosystem dynamics or attempting to solve insect-related problems may be good opportunities.

A subsidiary of this is providing clear actions and opportunities that students can take to help causes they care about. For example, getting students participating in a citizen science initiative can improve their self-confidence and sense of agency in dealing with environmental issues. Similarly, community- or locally-based efforts connect with students and increase these feelings of agency as well. Social justice issues may also connect with urban, at-risk, or underrepresented students, further increasing the benefits they receive from entomology programming. Instructors interested in promoting insect conservation within the classroom may seek out these opportunities for students to get directly involved.

4) *Maintain Positive Tone and Messaging surrounding insects and insect-related issues*

People respond more actively to environmental issues when they are surrounded by more positive, hopeful messages about them (Schultz, 2011; Simaika & Samways, 2018; Weinstein et al., 2015). Our findings have discovered that entomological lessons are already using this language. Therefore, lesson designers, instructors, and curriculum developers should continue this trend if insect conservation is an education priority. This becomes ever more important as the state of insect population declines become more clear to the scientific community.

Finally, either via local administration or larger public policy, more resources need to be provided to instructors to support entomological education. This includes accessibility to training, curricular support for insect instruction, financial resources to support larger projects, and time within schedules to complete interactive activities. On a similar level, programs that focus on urban, at-risk, underrepresented (including female) students and teachers should be given priority considering their significant potential to impact these groups.

Conclusions

The risk society faces from insect population declines makes better entomological education a must. There is great opportunity, but also a fair amount of risk, involved in improving entomological education. The lack of resources creates scenarios where new methods or ideas are difficult to implement and even more difficult to continue throughout a thorough evaluation process. Integrating conservation themes into these already sparse lessons may increase the resources required for execution. However, what this review has demonstrated is the potential of entomological education to fill more niches within the educational ecosystem than is currently being done. Between its effectiveness at illustrating different core concepts and engaging qualities, insects' and arthropods' natural diversity allows for an array of science learning opportunities that can deepen students' understanding of ecology, the scientific processes, and the world around them.

Acknowledgements

Funding for this project was given through an individual grant by the Undergraduate Research Opportunities Program (UROP) at the University of Colorado Boulder. Thank you to Dr. Lisa Corwin, Dr. Pieter Johnson, Dr. Andrea Feldman, Nicole Chlebek, and Erin Fried for providing mentorship, guidance, and research assistance for this project. Additional gratitude towards the insect biology instructors at CU Boulder, the CU Boulder Museum, the Butterfly Pavilion, and the CU Teach Program for providing essential background knowledge and additional support for the project in all its stages.

References

Anderson, B., Böhmelt, T., & Ward, H. (2017). Public opinion and environmental policy output: A cross-national analysis of energy policies in Europe. *Environmental Research Letters*, *12*(11), 114011. https://doi.org/10.1088/1748-9326/aa8f80

Annetta, L., Klesath, M., & Meyer, J. (2009). Taking Science Online: Evaluating Presence and Immersion through a Laboratory Experience in a Virtual Learning Environment for Entomology Students. *Journal of College Science Teaching*, *39*(1), 27–33.

Asshoff, R., Hallerbach, P., & Reinhardt, K. (2020). Teaching changes interest and attitudes of students towards bedbugs. *International Journal of Science Education*, 1–16. https://doi.org/10.1080/09500693.2020.1788745

(Athman) Ernst *, J., & Monroe, M. (2004). The effects of environment-based education on students' critical thinking skills and disposition toward critical thinking. *Environmental Education Research*, *10*(4), 507–522. https://doi.org/10.1080/1350462042000291038

Balmford, A. (2002). Why Conservationists Should Heed Pokemon. *Science*, *295*(5564), 2367b–22367. https://doi.org/10.1126/science.295.5564.2367b

Battersby, J. (1999). Does Environmental Education have 'Street Credibility' and the Potential to Reduce Pupil Disaffection Within and Beyond their School Curriculum? *Cambridge Journal of Education*, *29*(3), 447–459. https://doi.org/10.1080/0305764990290312

Bjerke, T., Østdahl, T., & Kleiven, J. (2003). Attitudes and activities related to urban wildlife: Pet owners and non-owners. *Anthrozoös*, *16*(3), 252–262. https://doi.org/10.2752/089279303786992125

Caduto, M. (1983). A Review of Environmental Values Education. *The Journal of Environmental Education*, *14*(3), 13–21. https://doi.org/10.1080/00958964.1983.9942657

Chawla, L. (1998). Significant Life Experiences Revisited: A Review of Research on Sources of Environmental Sensitivity. *The Journal of Environmental Education*, *29*(3), 11–21. https://doi.org/10.1080/00958969809599114

Chawla, L., & Cushing, D. F. (2007). Education for strategic environmental behavior. *Environmental Education Research*, *13*(4), 437–452. https://doi.org/10.1080/13504620701581539

Cheng, J. C.-H., & Monroe, M. C. (2012). Connection to Nature: Children's Affective Attitude Toward Nature. *Environment and Behavior*, *44*(1), 31–49. https://doi.org/10.1177/0013916510385082

Cornelisse, T. M., & Sagasta, J. (2018). The Effect of Conservation Knowledge on Attitudes and Stated Behaviors toward Arthropods of Urban and Suburban Elementary School Students. *Anthrozoös*, *31*(3), 283–296. https://doi.org/10.1080/08927936.2018.1455450

Crespo-Pérez, V., Kazakou, E., Roubik, D.W., Cárdenas, R.E. (2020). The importance of insects on land and in water: a tropical view. Current Opinion in Insect Science, 40. 31-38. https://doi.org/10.1016/j.cois.2020.05.016

Curtis, V., Aunger, R., & Rabie, T. (2004). Evidence that disgust evolved to protect from risk of disease. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *271*(suppl_4). https://doi.org/10.1098/rsbl.2003.0144

Dillon, J., Rickinson, M., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., & Benefield, P. (2006). The value of outdoor learning: Evidence from research in the UK and elsewhere. *School Science Review*, *87*(320), 107.

Duran, L. B., & Duran, E. (2004). *The 5E Instructional Model: A Learning Cycle Approach for Inquiry-Based Science Teaching*. 10.

Erwin, D. H. (1996). The mother of mass extinctions. *Scientific American*, *275*(1), 72-78.

Eyler, J., & Giles, D. E. (1999). *Where's the learning in service-learning?* (1. ed). Jossey-Bass.

Fančovičová, J., & Prokop, P. (2017). Effects of Hands-on Activities on Conservation, Disgust and Knowledge of Woodlice. *Eurasia Journal of Mathematics, Science and Technology Education*. https://doi.org/10.12973/ejmste/80817

Fisher-Maltese, C. (n.d.). *"We won't hurt you butterfly!" Second-graders become environmental stewards from experiences in a school garden*. 16.

Fisher-Maltese, C., & Zimmerman, T. D. (2015). *A Garden-Based Approach to Teaching Life Science Produces Shifts in Students' Attitudes toward the Environment*. 16.

Gangwani, K., & Landin, J. (2018). The Decline of Insect Representation in Biology Textbooks Over Time. *American Entomologist*, *64*(4), 252–257. https://doi.org/10.1093/ae/tmy064

Gerdes, A. B. M., Uhl, G., & Alpers, G. W. (2009). Spiders are special: Fear and disgust evoked by pictures of arthropods. *Evolution and Human Behavior*, *30*(1), 66–73. https://doi.org/10.1016/j.evolhumbehav.2008.08.005

Gin, L. E., Rowland, A. A., Steinwand, B., Bruno, J., & Corwin, L. A. (2018). Students Who Fail to Achieve Predefined Research Goals May Still Experience Many Positive Outcomes as a Result of CURE Participation. *CBE—Life Sciences Education, 17*(4), ar57. https://doi.org/10.1187/cbe.18-03-0036

Golick, D. A., Heng-Moss, T. M., Steckelberg, A. L., Brooks, David. W., Higley, L. G., & Fowler, D. (2013). Using Web-Based Key Character and Classification Instruction for Teaching Undergraduate Students Insect Identification. *Journal of Science Education and Technology*, *22*(4), 509–521. https://doi.org/10.1007/s10956-012-9410-z

Haefner, L. A., Friedrichsen, P. M., & Zembal-Saul, C. (2006). Teaching with Insects: An

Applied Life Science Course for Supporting Prospective Elementary Teachers' Scientific Inquiry. *The American Biology Teacher*, *68*(4), 206–212. https://doi.org/10.2307/4451968

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE*, *12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809

Hidi, S., & Renninger, K. A. (2006). The Four-Phase Model of Interest Development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Home • Monarch Butterfly Fund. (2020). Monarch Butterfly Fund. https://monarchconservation.org/

Hunt, T., Bergsten, J., Levkanicova, Z., Papadopoulou, A., St. John, O., Wild, R., Hammond, P.M., Ahrens, D., Balke, M., Caterino., M.S., Gómez-Zurita, J., Ribera, I., Barraclough, T.G., Bocakova, M., Bocak, L., Vogler, A.P. (2007). A Comprehensive Phylogeny of Beetles Reveals the Evolutionary Origins of a Superradiation. *Science*, *318*(5858), 1913-1916.

Ingram, & Golick. (2018). The Six-Legged Subject: A Survey of Secondary Science Teachers' Incorporation of Insects into U.S. Life Science Instruction. *Insects*, *9*(1), 32. https://doi.org/10.3390/insects9010032

Jackson, A. (2018). Sweet Innovation: Garrison Forest students become campus beekeepers. *Childhood Education*, *94*(6), 13–19. https://doi.org/10.1080/00094056.2018.1540190

Jacobi, F., Wittchen, H.-U., Hölting, C., Höfler, M., Pfister, H., Müller, N., & Lieb, R. (2004). Prevalence, co-morbidity and correlates of mental disorders in the general population:

Results from the German Health Interview and Examination Survey (GHS). *Psychological Medicine*, *34*(4), 597–611. https://doi.org/10.1017/S0033291703001399

Jankielsohn, A. (2018). The Importance of Insects in Agricultural Ecosystems. *Advances in Entomology*, *6*. 62-73. https://doi.org/10.4236/ae.2018.62006.

Janzen, D. H., & Hallwachs, W. (2019). Perspective: Where might be many tropical insects? *Biological Conservation*, *233*, 102–108. https://doi.org/10.1016/j.biocon.2019.02.030

Jaus, H. H. (1984). The Development and Retention of Environmental Attitudes in Elementary School Children. *The Journal of Environmental Education*, *15*(3), 33–36. https://doi.org/10.1080/00958964.1984.9942679

Kellert, S. R. (1985). Attitudes toward Animals: Age-Related Development among Children. *The Journal of Environmental Education*, *16*(3), 29–39. https://doi.org/10.1080/00958964.1985.9942709

Klingenberg, K. (2014). 'Primärerfahrung' with living animals in contrast to educational videos: A comparative intervention study. *Journal of Biological Education*, *48*(2), 105–112. https://doi.org/10.1080/00219266.2013.849285

Kuiper, J. (1994). Student ideas of science concepts: Alternative frameworks? *International Journal of Science Education*, *16*(3), 279–292. https://doi.org/10.1080/0950069940160303

Leather, S. R. (2018). "Ecological Armageddon" - more evidence for the drastic decline in insect numbers: Insect declines. *Annals of Applied Biology*, *172*(1), 1–3. https://doi.org/10.1111/aab.12410

Light, J. (2001). Rethinking the Digital Divide. *Harvard Educational Review*, *71*(4), 709–734. https://doi.org/10.17763/haer.71.4.342x36742j2w4q82

Lister, B. C., & Garcia, A. (2018). Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proceedings of the National Academy of Sciences*, *115*(44), E10397–E10406. https://doi.org/10.1073/pnas.1722477115

Lockwood, J. A. (2013). *The infested mind: Why humans fear, loathe, and love insects*. Oxford University Press.

Looy, H., & Wood, J. R. (2006). Attitudes Toward Invertebrates: Are Educational “Bug Banquets” Effective? *The Journal of Environmental Education*, *37*(2), 37–48. https://doi.org/10.3200/JOEE.37.2.37-48

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: Cognitive, metacognitive, social, material and epistemological contributions. *Educational Review*, *64*(4), 471–492. https://doi.org/10.1080/00131911.2011.628748

Lucky, A., Branham, M., & Atchison, R. (2019). Collection-Based Education by Distance and Face to Face: Learning Outcomes and Academic Dishonesty. *Journal of Science Education and Technology*, *28*(4), 414–428. https://doi.org/10.1007/s10956-019-9770-8

Lurie-Luke, E. (2014) Product and technology innovation: What can biomimicry inspire? Biotechnology Advances, 32(8). 1494-1505. https://doi.org/10.1016/j.biotechadv.2014.10.002

Mason, M., Aihara-Sasaki, M., & Grace, J. K. (2013). *Measuring the Impact of Termite Prevention Curricula in Hawaii Public Schools in an Area-Wide Extension Program*. 9.

Misof, B., Liu, S., Meusemann, K., Peters, R. S., Donath, A., Mayer, C., Frandsen, P. B., Ware, J., Flouri, T., Beutel, R. G., Niehuis, O., Petersen, M., Izquierdo-Carrasco, F., Wappler, T., Rust, J., Aberer, A. J., Aspock, U., Aspock, H., Bartel, D., … Zhou, X. (2014). Phylogenomics resolves the timing and pattern of insect evolution. *Science*, *346*(6210), 763–767. https://doi.org/10.1126/science.1257570

Monarch Butterfly Conservation | Xerces Society. (2020). https://xerces.org/monarchs

New, T. R. (Ed.). (2012). *Insect conservation: Past, present and prospects*. Springer.

Page, B. I., & Shapiro, R. Y. (1983). Effects of Public Opinion on Policy. *American Political Science Review*, *77*(1), 175–190. https://doi.org/10.2307/1956018

Pearson, G. A., Skinner, K. M., & Hoback, W. W. (2007). Rearing the Masses: Defining Competencies for Entomological Literacy. *American Entomologist*, *53*(4), 216–223. https://doi.org/10.1093/ae/53.4.216

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Pohl, G. (2009). Why we kill bugs—The case for collecting insects. *Newsletter of the Biological Survey of Canada (Terrestrial Arthropods)*, *28*(1), 10–17.

Prokop, P., & Fančovičová, J. (2010). The association between disgust, danger and fear of macroparasites and human behaviour. *Acta Ethologica*, *13*(1), 57–62. https://doi.org/10.1007/s10211-010-0075-4

Prokop, P., Usak, M., Erdogan, M., & Bahar, M. (2011). Slovakian and Turkish students' fear, disgust, and percieved danger of invertebrates. *Hacettepe University Journal of Education*, *40*, 344–352.

Randler, C., Hummel, E., & Prokop, P. (2012). Practical Work at School Reduces Disgust and Fear of Unpopular Animals. *Society & Animals*, *20*(1), 61–74. https://doi.org/10.1163/156853012X614369

Rinfret, S. R., & Pautz, M. C. (2019). *US environmental policy in action* (2nd ed.). Springer Berlin Heidelberg.

Robinette, M., & Noblet, R. (2009). Service-Learning in Entomology: Teaching, Research, and Outreach Domestically and Abroad. *Journal of Higher Education Outreach and Engagement*, *13*(4), 135.

Rowland, A. A., Knekta, E., Eddy, S., & Corwin, L. A. (2019). Defining and Measuring Students' Interest in Biology: An Analysis of the Biology Education Literature. *CBE—Life Sciences Education*, *18*(3), ar34. https://doi.org/10.1187/cbe.19-02-0037

Sammet, R., & Dreesmann, D. (2017). What Do Secondary Students Really Learn during Investigations with Living Animals? Parameters for Effective Learning with Social Insects. *Journal of Biological Education*, *51*(1), 26–43. https://doi.org/10.1080/00219266.2016.1150873

Sammet, R., Kutta, A.-M., & Dreesmann, D. (2015). Hands-on or Video-based Learning with ANTicipation? A Comparative Approach to Identifying Student Motivation and Learning Enjoyment During a Lesson about Ants. *Journal of Biological Education*, *49*(4), 420–440. https://doi.org/10.1080/00219266.2014.1002518

Samways, M. J. (2007). Rescuing the extinction of experience. *Biodiversity and Conservation*, *16*(7), 1995–1997. https://doi.org/10.1007/s10531-006-9144-4

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, *232*, 8–27. https://doi.org/10.1016/j.biocon.2019.01.020

Save The Bees^{TM}. (2020). Bee Mission. https://beemission.com/

Schindel Dimick, A. (2016). Exploring the Potential and Complexity of a Critical Pedagogy of

Place in Urban Science Education: EXPLORING CRITICAL PEDAGOGY OF PLACE. *Science Education*, *100*(5), 814–836. https://doi.org/10.1002/sce.21233

Schönfelder, M. L., & Bogner, F. X. (2017). Two ways of acquiring environmental knowledge: By encountering living animals at a beehive and by observing bees via digital tools. *International Journal of Science Education*, *39*(6), 723–741. https://doi.org/10.1080/09500693.2017.1304670

Schultz, P. W. (2011). Conservation Means Behavior: Conservation Means Behavior. *Conservation Biology*, *25*(6), 1080–1083. https://doi.org/10.1111/j.1523-1739.2011.01766.x

Simaika, J. P., & Samways, M. J. (2010). Biophilia as a Universal Ethic for Conserving Biodiversity: Biophilia and Conservation of Biodiversity. *Conservation Biology*, *24*(3), 903–906. https://doi.org/10.1111/j.1523-1739.2010.01485.x

Simaika, J. P., & Samways, M. J. (2018). Insect conservation psychology. *Journal of Insect Conservation*, *22*(3–4), 635–642. https://doi.org/10.1007/s10841-018-0047-y

Simmons, B. I., Balmford, A., Bladon, A. J., Christie, A. P., De Palma, A., Dicks, L. V., Gallego-Zamorano, J., Johnston, A., Martin, P. A., Purvis, A., Rocha, R., Wauchope, H. S., Wordley, C. F. R., Worthington, T. A., & Finch, T. (2019). Worldwide insect declines: An important message, but interpret with caution. *Ecology and Evolution*, *9*(7), 3678–3680. https://doi.org/10.1002/ece3.5153

Soga, M., & Gaston, K. J. (2016). Extinction of experience: The loss of human-nature interactions. *Frontiers in Ecology and the Environment*, *14*(2), 94–101. https://doi.org/10.1002/fee.1225

Steinke, D., Breton, V., Berzitis, E., & Hebert, P. D. N. (2017). The School Malaise Trap

Program: Coupling educational outreach with scientific discovery. *PLOS Biology*, *15*(4), e2001829. https://doi.org/10.1371/journal.pbio.2001829

Tewksbury, J. J., Anderson, J. G. T., Bakker, J. D., Billo, T. J., Dunwiddie, P. W., Groom, M. J., Hampton, S. E., Herman, S. G., Levey, D. J., Machnicki, N. J., del Rio, C. M., Power, M. E., Rowell, K., Salomon, A. K., Stacey, L., Trombulak, S. C., & Wheeler, T. A. (2014). Natural History's Place in Science and Society. *BioScience*, *64*(4), 300–310. https://doi.org/10.1093/biosci/biu032

The Honeybee Conservancy—Saving the Bees through Outreach and EducationThe Honeybee Conservancy. (2020). https://thehoneybeeconservancy.org/

Thomas, C. D., Jones, T. H., & Hartley, S. E. (2019). "Insectageddon": A call for more robust data and rigorous analyses. *Global Change Biology*, *25*(6), 1891–1892. https://doi.org/10.1111/gcb.14608

U.S. GSA. (2020). *About CitizenScience.gov*. About CitizenScience.Gov. https://www.citizenscience.gov/about/

Wagler, R., & Wagler, A. (n.d.). *Arthropods: Attitude and incorporation in preservice elementary teachers*. 22.

Walker, K. A. (2018). Gender Gap in Professional Entomology: Women Are Underrepresented in Academia and the U.S. Government. *Annals of the Entomological Society of America*, *111*(6), 355–362. https://doi.org/10.1093/aesa/say030

Webster, N. (2006). Incorporating Service Learning and Extension in Inner City Middle Schools: A Model for Future Programming. *Journal of Extension*, *44*(1).

Weeks, F., & Oseto, C. (2018). Interest in Insects: The Role of Entomology in Environmental Education. *Insects*, *9*(1), 26. https://doi.org/10.3390/insects9010026

Weinstein, N., Rogerson, M., Moreton, J., Balmford, A., & Bradbury, R. B. (2015). Conserving nature out of fear or knowledge? Using threatening versus connecting messages to generate support for environmental causes. *Journal for Nature Conservation*, *26*, 49–55. https://doi.org/10.1016/j.jnc.2015.04.002

Wells, N. M., & Lekies, K. S. (2006). Nature and the Life Course: Pathways from Childhood Nature Experiences to Adult Environmentalism. *Children, Youth and Environments*, *16*(1), 1–24. JSTOR.

Wenning, C. (2008). Dealing more effectively with alternative conceptions in science. *Journal of Physics Teacher Education Online*, *5*(1), 11–19.

Wilde, M., Hußmann, J. S., Lorenzen, S., Meyer, A., & Randler, C. (2012). Lessons with Living Harvest Mice: An empirical study of their effects on intrinsic motivation and knowledge acquisition. *International Journal of Science Education*, *34*(18), 2797–2810. https://doi.org/10.1080/09500693.2012.654829

Zenger, J. T., & Walker, T. J. (2000). Impact of the Internet on Entomology Teaching and Research. *Annual Review of Entomology*, *45*(1), 747–767. https://doi.org/10.1146/annurev.ento.45.1.747

Zylstra, M. J., Knight, A. T., Esler, K. J., & Le Grange, L. L. L. (2014). Connectedness as a Core Conservation Concern: An Interdisciplinary Review of Theory and a Call for Practice. *Springer Science Reviews*, *2*(1–2), 119–143. https://doi.org/10.1007/s40362-014-0021-3

Appendix 1a: List of Studied Lesson Plans

#	Title	Author(s)	Year
1	Inquiring about Isopods	Adams	2006
2	Entomology: Promoting Creativity in the Science Lab	Akcay	2013
3	Buzz into Action: How to Identify an Insect	Alexander	2012
4	Buzz into Action: Insect Encounters	Alexander	2012
5	Buzz into Action: Insect Metamorphosis	Alexander	2012
6	BiA: Insect Venn Diagrams	Alexander	2012
7	BiA: Pollination Party Relay Race	Alexander	2012
8	BiA: Pollinator Gardens	Alexander	2012
9	BiA: Camouflaged Critters	Alexander	2012
10	BiA: Amazing Insect Migration	Alexander	2012
11	BiA: Insect Mouthparts	Alexander	2012
12	BiA: Antennae Communication	Alexander	2012
13	BiA: Audible Insects	Alexander	2012
14	BiA: Water Bugs, Insects as Indicators	Alexander	2012
15	BiA: Delightful Decomposers	Alexander	2012
16	BiA: What's all the Buzz About?	Alexander	2012
17	BiA: Seasonal Discoveries Journal	Alexander	2012
18	BiA: Insect Art	Alexander	2012
19	BiA: Bee Factory	Alexander	2012
20	BiA: Colony Collapse Town Meeting	Alexander	2012
21	BiA: Insect Choices	Alexander	2012
22	BiA: Insect Habitat Web	Alexander	2012
23	Counting a Culture of Mealworms	Ashbrook	2007
24	Entomological Research in the Classroom: The Dispersal of Biological Control Agents	Goode and Halbritter	2019
25	What's Inside a Termite's Gut?	Morales, Rowton, Anderson, and Yourick	2017

26	Bug Talk: A Learning Module on Insect Communication	Bergman	2010
27	Honeybees, Butterflies, and Ladybugs: Partners to Plants	Campbell	2009
28	Of Maggots and Murder: Forensic Entomology in the Classroom	Carloye	2003
29	Awesome Aggregations	Constible & Lee	2006
30	Promoting Puzzlement and Inquiry with Pillbugs	Cox-Petersen & Olson	2001
31	Exploring Insect Vision	Damonte	2005
32	Be a Bee and Other Approaches to Introducing Young Children to Entomology	Danoff-Burg	2002
33	There’s Life in Those Dead Logs	Biggs, Miller, and Hall	2006
34	Ladybugs Across the Curriculum	Dias Ward & Dias	2004
35	Simply Butterflies	Dobey & Springer	2002
36	Bringing the Outside In: Insects and their Galls	Farenga, Joyce, Ness & Wilkens	2003
37	Bee-coming Entomologists	Farrand, Oakes, & Deeg	2019
38	Investigation -- Insects!	Fay	2000
39	Teaching with Live Insects	Fisher & Lorenz-Reaves	2018
40	Teaching About Behavior with the Tobacco Hornworm	Goodman, Jeanne, & Sutherland	2001
41	Investigating Aquatic Insect Emergence: A Demonstration of the 5E Learning Cycle	Heinrich, Robson, & Baxter	2017
42	What's the Buzz on Bees?	Holt-Taylor	2017
43	Gaining Traction	James & Matthews	2017
44	Forensic Entomology for the Laboratory-Based Biology Classroom	Miller	2002
45	Bee Wild About Pollinators	Johnson, Kil, Evans, & Hollingsworth Koomen	2014
46	Tiny, Powerful, Awesome Ants!	Tate	2007
47	Through the Bugscope	Hadley and Korb	2007
48	Drosophila & Beer an Experimental Laboratory Exercise	Kurvink	2004

49	What's the Buzz?	Hinman	2000
50	Waiting for the Monarch	Forrest and Hechter	2017
51	Is a Mealworm Really a Worm?	Lott and Read	2012
52	Don't Swat that Fly! Using House Flies in an Inquiry Activity	McKay, Ross, Yanowitz, & Vanderpool	2014
53	Insect Keepers	Moore, Chessin, & Theobald	2010
54	Please Pass the Pollen	NSTA	2009
55	Prepare an Ant Picnic for Science	Nugent	2018
56	Exploring Sound with Insects	Robertson & Meyer	2010
57	What's Bugging You?: A 5E Learning Cycle Introduces Insect Classification	Brown	2006
58	Let Monarchs Rule	Shimkanin & Murphy	2007
59	Meet the Mealworms	Staller	2005
60	Visual Literacy in Life Science: Insect Metamorphosis	Vasquez, Comer, Troutman	2010
61	Exploring Terrestrial Isopods	Wagler	2017
62	The Wonders of Terrestrial Arthropods	Wagler	2013
63	Chow Down: Using Madagascar Hissing Cockroaches to Explore Basic Nutrition Concepts	Wagler	2009
64	The Dark Side of the Tube	Wagler and Wagler	2014

Appendix 1b: List of Studied Journal Articles

#	Title	Author(s) and Year
1	Taking Science Online: Evaluating Presence and Immersion Through a Laboratory Experience in a Virtual Learning Environment for Entomology Students	Annetta et al. (2009)
2	Teaching changes interest and attitudes of students towards bedbugs	Asshoff et al. (2020)
3	The Effect of Conservation Knowledge on Attitudes and Stated Behaviors toward Arthropods of Urban and Suburban Elementary School Students	Cornelisse & Sagasta (2018)
4	Effects of Hands-on Activities on Conservation, Disgust and Knowledge of Woodlice	Fančovičová & Prokop (2017)
5	“We won’t hurt you butterfly!” Second-graders become environmental stewards from experiences in a school garden	Fisher-Maltese (2016)
6	The Decline of Insect Representation in Biology Textbooks Over Time	Gangwani & Landin (2018)
7	Using Web-Based Key Character and Classification Instruction for Teaching Undergraduate Students Insect Identification	Golick et al. (2013)
8	Teaching with Insects: An Applied Life Science Course for Supporting Prospective Elementary Teachers' Scientific Inquiry	Haefner et al. (2006)
9	The Six-Legged Subject: A Survey of Secondary Science Teachers’ Incorporation of Insects into U.S. Life Science Instruction	Ingram & Golick (2018)
10	Sweet Innovation: Garrison Forest students become campus beekeepers	Jackson (2018)
11	Attitudes Toward Invertebrates: Are Educational "Bug Banquets" Effective?	Looy & Wood (2006)
12	Collection-Based Education by Distance and Face to Face: Learning Outcomes and Academic Dishonesty	Lucky et al. (2019)
13	Measuring the Impact of Termite Prevention Curricula in Hawaii Public Schools in an Area-Wide Extension Program	Mason et al. (2013)
14	Service-Learning in Entomology: Teaching, Research, and Outreach Domestically and Abroad	Robinette & Noblet (2009)
15	Hands-on or Video-based Learning with ANTicipation? A Comparative Approach to Identifying Student Motivation and Learning Enjoyment During a Lesson about Ants	Sammet et al. (2015)
16	What Do Secondary Students Really Learn during Investigations with Living Animals? Parameters for Effective Learning with Social Insects	Sammet & Dreesmann (2017)

17	Two ways of acquiring environmental knowledge: by encountering living animals at a beehive and by observing bees via digital tools	Schönfelder & Bogner (2017)
18	The School Malaise Trap Program: Coupling educational outreach with scientific discovery	Steinke et al. (2017)
19	Arthropods: Attitude and incorporation in preservice elementary teachers	Wagler & Wagler (2011)
20	Interest in Insects: The Role of Entomology in Environmental Education	Weeks & Oseto (2018)
21	Impact of the Internet on Entomology Teaching and Research	Zenger & Walker (2000)

Appendix 2: Search Keywords and Results

#	Term 1	Term 2	Term 3	Connect 1	Connect 2	Result Count	Engine
1	"entomology"	"education"		AND		61	Web of Science
2	"entomology"	"learning"		AND		37	Web of Science
3	"insect"	"education"		AND		331	Web of Science
4	"insect"	"education"	"teaching"	AND	AND	19	Web of Science
5	"insect"	"education"	"learning"	AND	AND	29	Web of Science
6	"insect"	"school"		AND		133	Web of Science
14	"entomology"	"student"		AND		19	Web of Science
15	"insect"	"student"		AND		68	Web of Science
15	"entomology"	"classroom"		AND		7	Web of Science
16	"insect"	"classroom"		AND		15	Web of Science
8	"insect"	"education"		AND		312	ERIC
9	"entomology"	"education"		AND		393	ERIC
12	"entomology"					615	ERIC
13	"entomology"	"science education"		AND		216	ERIC
17	"entomology"	"result"		AND		96	ERIC
18	"entomology"	"outcome"		AND		25	ERIC