FEATURE ARTICLE

An Exercise on Data-Based Decision Making: Comparing the Sustainability of Meat & Edible Insects

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ABSTRACT

The ability to make criteria-based and thought-out decisions in everyday life as well as to answer questions pertaining to society at large, such as those regarding climate change and the loss of biodiversity, is becoming more and more important against the backdrop of an increasingly complex world with a wide range of options for action or inaction. Using the method of "data-based decision making," this article presents a decision-making strategy for improving the evaluation competence of students that is particularly suitable for teaching socioscientific issues in the context of sustainable development. Using the example of human consumption of insects (sometimes termed "entomophagy," although this term is defined as the consumption of insects by any organism), the students will evaluate the potential for insects as an alternative, sustainable source of protein as compared with conventional meat.

Key Words: *data-based decision making; decision-making strategies; sustainability; entomophagy; meat consumption; world population.*

○ Introduction

According to the *Next Generation Science Standards* (NGSS Lead States, 2013) students should strive to learn about "the influence of science, engineering, and technology on society and the natural world" (NGSS Lead States, 2013, vol. 2, p. 108). Furthermore, they should recognize "that scientific discoveries and technological decisions affect human society and the natural environment," and "that people make decisions for [both] social and environmental reasons" (NGSS Lead States, 2013, vol. 2, p. 109). Modern biology classes should, therefore, enable students to deal with current and complex issues pertaining to sustainable development, learning to evaluate them adequately and make deliberate decisions with positive ethical outcomes.

> *"Insect species suitable for human consumption are known to come from almost all insect orders."*

In the teaching unit described here, students evaluate the sustainability of food made with insects as a major ingredient – a modern and controversially viewed meat alternative – in comparison with conventional meat. Students use the method of "data-based decision making" (cf. Bögeholz, 2006) to reflect on whether they would, or should, use insects as a substitute for meat. This method can be applied to other topics of biology lessons, such as questions concerning stem cell research or the approval of genetically modified foods.

○ Factual Information on Meat Consumption & Edible Insects

Ecological, Social & Health Consequences of Global Meat Consumption

The production and consumption of meat are regarded collectively as the main cause of numerous negative ecological and social impacts of our time (Dossey et al., 2016a). They are major drivers of biodiversity loss and the excessive loading of biogeochemical material cycles with nitrogen and phosphate compounds. No other consumer good in the world requires as much land for development as that required for the production of meat. It has been proposed that the further intensification of meat production and consumption could increase the share of climate-damaging gases by almost 80% by 2050 (Heinrich-Böll-Stiftung, 2018). The high demand for animal products in addition to the feed required for them further exacerbates the global hunger problem and leads to an unequal distribution of food.

Nevertheless, according to the U.S. Department of Agriculture, meat consumption in the United States has continued to rise in
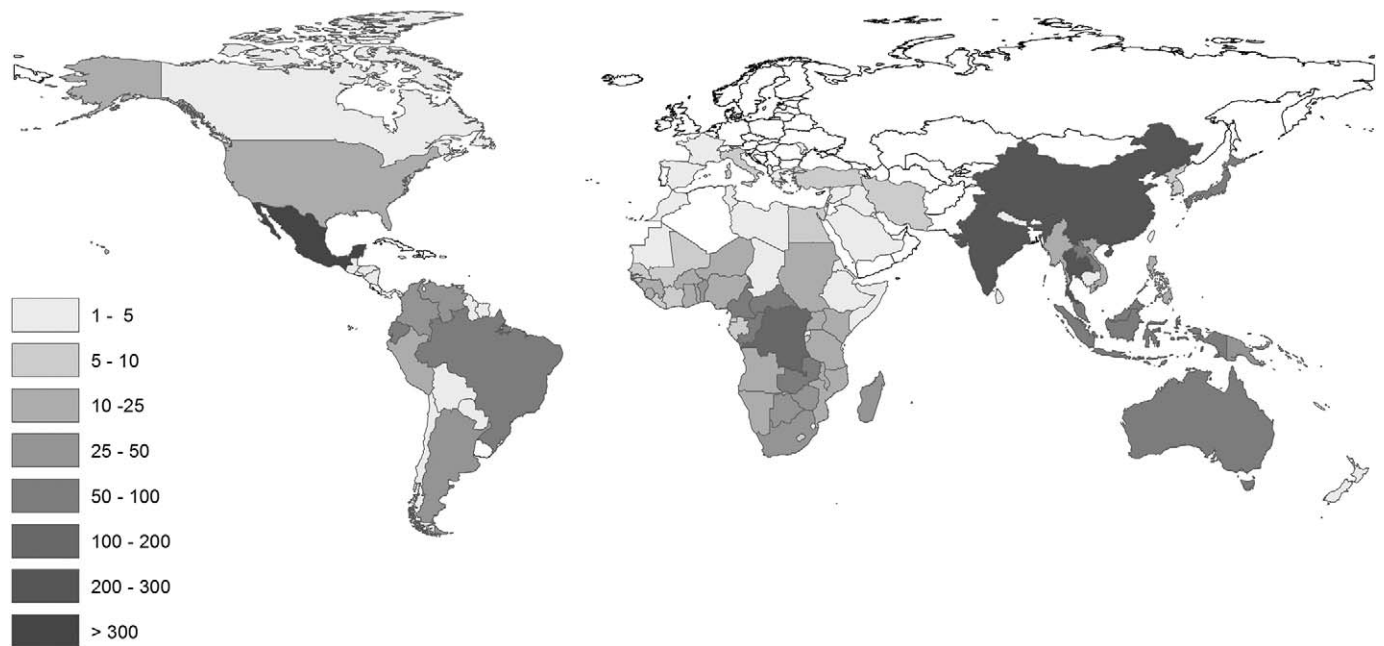
Figure 1. Numbers of recorded insect species eaten, by country. Source: Ron van Lammeren, Centre of Geoinformation Science and Remote Sensing, Wageningen University.

recent decades and sets new records year after year. More specifically, annual meat consumption per capita increased from 98.5 kg in 2017 to 99.6 kg in 2018 and was forecast to grow to more than 100 kg in 2019 (Haley, 2019). For comparison, global meat consumption was estimated at 43.7 kg/capita/year in 2018, which equals a total of 335 million tons of meat – about 1.5% more than in 2017 (OECD/FAO, 2018). This trend will continue to increase in view of a steadily growing world population unless behaviors, preferences, and food choice values are changed. According to the FAO of the United Nations, the world population will increase by about one-third by 2050, from about 7.5 billion today to nearly 10 billion (United Nations, 2017). Simultaneously, global meat consumption is expected to rise to 49 kg/capita/year in 2050 (Bruinsma, 2003; Alexandratos & Bruinsma, 2012). In addition to the already high per capita consumption of animal-sourced food in Western industrial countries, there is an increasing demand for such food in developing countries due to rising incomes and a growing middle class (OECD/FAO, 2018, p. 28).

Aside from the health risks of greater meat consumption, such as the increased risks of cardiovascular disease, cancer, and obesity (Tilman & Clark, 2014), rising demands for mammal and poultry products heighten the potential for aggravating the environmental and social problems associated with conventional meat production. Therefore, further intensification of current industrial agriculture is not a viable long-term solution with which to feed a growing or even stabilized human population. Instead, there is a need to change eating habits at the individual level toward the increased use of sustainable protein sources. In addition to vegetable proteins from lupines or soybeans, legumes (beans), in-vitro meat and insects have recently been discussed as modern and sustainable possible alternatives to conventional meat (Dossey et al., 2016a, b; Nadathur et al., 2017; Lamsal et al., 2019).
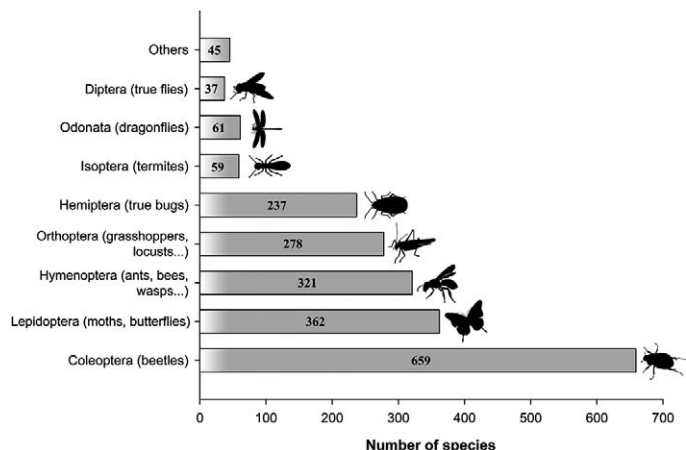

Figure 2. Numbers of globally recorded edible insect species, by group (data based on Jongema, 2017).

Consumption of Insects Worldwide & in the United States

The FAO estimates that two billion people, or more than one-quarter of the world's population, use insects as food (Dossey et al., 2016a). Particularly in the subtropical and tropical regions of South and Central America, Africa, and South and East Asia, insects have been an important part of human nutrition for thousands of years. The world leader – in terms of the number of recorded insect species eaten – is Mexico, with more than 549 consumed insect species (Figure 1).

Currently, it is assumed that 2111 insect species are consumed by humans (Jongema, 2017). Insect species suitable for human consumption are known to come from almost all insect orders (Figure 2). The most commonly consumed insect group in the world are beetles (Coleoptera), representing 31% of total edible

insect species. Mainly, it is the larvae that are eaten, but the imagoes, which is the last stage an insect attains during its metamorphosis, may be consumed as well. The second most common food is butterflies (Lepidoptera) at 18% of total edible insect species. Bees, wasps, and ants (Hymenoptera) (14% of total edible insect species) are the third most consumed group of insects (Fiebelkorn, 2017).

While the consumption of insects is widely accepted in large parts of Asia, South America, and Africa, insects are considered novel food products in Western industrial nations such as the United States. Psychological factors such as food neophobia, the fear of new foods, and disgust with insects play a crucial role in limiting the introduction and marketing of insects as an alternative source of animal protein (Baker et al., 2018). However, psychological and cultural prejudices against insects have not discouraged entrepreneurs in Europe and the United States from marketing insects as a healthy and sustainable food (Dossey et al., 2016b). Particularly in the United States, numerous start-ups dedicated to entomophagy have collected millions of dollars in venture capital in recent years. Many of these companies are trying to bring products to the market where the insects themselves are no longer recognizable. This is being done by grinding insects (e.g., crickets) into a powder (e.g., "cricket powder"), paste, or liquid ingredient and mixing it into more commonly recognized food products as a protein supplement or functional or flavor ingredient (Dossey et al., 2016b). Most consumers are unaware that, in principle, we already eat insects every day unintentionally – potentially up to two pounds a year (Mishan, 2018). They, or at least fragments of them, are found in peanut butter, frozen broccoli, chocolate, and spice packaging, all of which are legally approved in limited quantities by the U.S. Food and Drug Administration (FDA). For example, chocolate may contain, on average, up to 60 insect pieces per 100 g, while curry powder may hold up to 100 insect pieces per 25 g (FDA, 2018).

Environmental & Health Benefits of Insects as Food

As compared with the conventional animal husbandry of chickens, pigs, and cattle, insect production has many advantages with respect to selected sustainability indicators. The edible portion, at 80–100% of their total body, is considerably higher than that among conventional livestock, where only about 50% of the animal is used as food. At the same time, insects have a higher feed-conversion ratio, as they are poikilothermic, in contrast to homoiothermic farm animals such as chickens, pigs, or cattle. Thus, insects do not need energy to maintain their body temperature and can use it directly for growth. However, this is also one of the main criticisms of sustainable insect breeding. In order for insects to grow and reproduce well, they require a certain operating temperature, which nontemperate climates would have to artificially supply for several months. The energy required for this would be similar to that required for breeding conventional livestock such as chickens. However, more sustainable production – in terms of energy use – of insects would absolutely be possible in the tropics due to the more favorable climatic conditions found there. This, of course, depends on the temperature and environmental conditions of the insect species being farmed. In addition, insects have a lower CO_2

footprint over their entire life cycle. In contrast with conventional livestock farming, the production of other greenhouse gases such as CH_4 and N_2O in insect production is also much lower. Even water and land use can be reduced due to the considerably lower demands of insects. Additionally, insects can be cultivated on waste streams such as food wastes and recycled into valuable protein for food and feed (Dossey et al., 2016a; Fiebelkorn, 2017).

As various insect species contain high-quality animal protein, fat with a high content of unsaturated fatty acids, and numerous vitamins and minerals, they are generally described as nutritious and sufficient for a balanced diet. However, insects are not all the same – that is, their nutritional values vary relatively strongly depending on the insect species, feed composition, and husbandry conditions. From a nutritional point of view, their great potential is best illustrated by considering selected insect species that are already consumed and produced in large quantities for human consumption. Insect species such as mealworms (Tenebrio molitor) and house crickets (Acheta domesticus) have higher energy, protein, and fat contents than traditional animal protein sources such as chickens, pigs, or cattle (van Huis et al., 2013; Dossey et al., 2016a; see Table 1). Also, insects pose a low risk for the transmission of zoonotic diseases and human viruses such as H1N1, COVID-19, or BSE. Moreover, there have been no findings of the transmission of parasites to humans by already available insect-based foods (Fiebelkorn, 2017).

○ A Short Introduction to Data-Based Decision Making in Biology Classes

In this lesson, students learn to use the method of "data-based decision making" to make independent and, above all, well-founded decisions between different options for choice or action at the end of an evaluation and assessment process based on concrete topics in the context of sustainable development. Instead of intuitive decisions or a simple pros-and-cons lists, this method provides students a suitable tool for dealing with factually and ethically complex issues.

Students go through four consecutive steps of data-based decision making: (1) development of a factual model, (2) agreement on a value model, (3) systematic evaluation using an evaluation table, and (4) critical discussion of the evaluation's result. To simplify and accelerate the evaluation process in class, they can be given a pre-structured evaluation table (Table 2). The evaluation should be carried out from the student's personal perspective. Alternatively, students could take on different roles for the evaluation (e.g., nutritionist, consumer, farmer, meat worker), which may encourage them to speculate on what some (unknown) members of the population, not directly involved in the classroom discussion, might want and think.

The number of sustainability indicators to be selected can be differentiated according to the respective class level. In lower grades, fewer indicators and/or easy-to-understand indicators such as water consumption or land use (Table 1) should be used. In addition, the complexity and profundity of the scientific data can be adapted to the different grades. For example, greenhouse gas emissions and their composition or calculation can be dealt with much more intensively in higher grades.

Table 1. Resource use, environmental impact parameters, and nutrient composition of mealworms (larvae) and crickets (imagoes) in comparison with conventional livestock.

Parameter	Mealworms	Crickets	Chicken	Pork	Beef
Land use (m^2/kg)	18	–	42–52	47–64	144–258
Water use (L/kg)	4,341[1]	2,000	4,325[2]	5,988[2]	15,415[2]
Energy use (MJ/kg)	173	–	80–152	95–236	177–273
Production of greenhouse gas equivalents (g/kg mass gain)	8	2	–	1,130	2,850
Production of ammonia pollution (mg/day/kg mass gain)	1	142	–	1,920	–
Feed conversion ratio (kg food input/kg mass gain)	2.2	2.1	4.5	9.1	25
Percentage of digestible biomass (%)	100	80	55	55	40[3]
Protein content (g/100 g digestible biomass)	49.1	66.6	22.2	22.0	21.2
Fat content (g/100 g digestible biomass)	35.0	22.1	6.2	2.0	4.0
Energy content (kcal/100 g digestible biomass)	554	455	145	106	121

Notes: The values for chicken refer to 100 g of breast meat; those for pork and beef refer to 100 g sirloin. For insects, all values refer to unprocessed and raw animals. Land use = area in square meters to produce 1 kg of edible animal mass; water use = amount of water in liters to produce 1 kg of edible animal mass; energy use in megajoules (MJ) to produce 1 kg of edible animal mass (1 MJ = 239 kcal); production of greenhouse gas equivalents in grams per kilogram of body mass gain; feed conversion ratio = feed input in kilograms required to produce 1 kg of edible animal mass. A dash indicates that no data have been collected for the respective parameter to date. Sources: Dossey et al. (2016b) [changed after Fiebelkorn 2017; including the following: [1]Miglietta et al. (2015), [2]Mekonnen und Hoekstra (2010), and [3]van Huis und Tomberlin (2017)].

Table 2. Insects versus beef: evaluation table for the method of "data-based decision making" using the example of insects as meat substitutes.

Criterion	Evaluation	Option 1: Insects		Option 2: Meat (Beef)	
		Points	Value	Points	Value
CO_2 emissions	3	1	$3 \times 1 = 3$	2	$3 \times 2 = 6$
Price	2	4	$2 \times 4 = 8$	1	$2 \times 1 = 2$
. . .[a]					
Sum		11 points		8 points	

[a] The table is to be completed by the students with further indicators (e.g., land use, water use, energy use, nutrition, taste, availability, animal welfare).

Four Steps of Data-Based Decision Making

Development of a Factual Model
In this first step, students consider evaluation criteria they personally find relevant to the given subject matter (e.g., CO_2 emissions, water use, price). Working individually or as partners, they are asked to identify a total of up to 10 evaluation criteria they consider decisive for the choice between the individual courses of action and enter them in the first column of Table 2. In addition to the criteria already discussed in the previous teaching phases or introduced by means of the newspaper article provided (Figure 4), the students can consider further criteria of their own.

Reaching an Agreement on a Value Model
In the second step, each student evaluates the individual criteria according to their importance (i.e., 1 = unimportant,

2 = important, 3 = very important). Since different students have different values, this decision is up to each one of them and is likely to vary. These points are entered in the second column of Table 2.

Systematic Evaluation Using an Evaluation Table
The individual criteria (e.g., CO_2 emissions, price, water use, land use) are now to be evaluated systematically; a total of six points are available for each criterion. The points are to be distributed among the various options for action for each criterion. If this has been applied to all criteria, the final value is calculated by simple multiplication and then summed. The sum indicates which option would be the most sustainable choice in terms of calculation, thus giving students an initial orientation but not an absolute decision (Table 2).

Figure 3. Insect burger and its raw ingredient, buffalo worms (*Alphitobius diaperinus*). The two images can be used as introductory material for teaching about "edible insects" within the framework of Education for Sustainable Development (© Bugfoundation, Liza Ullmann).

Critical Discussion of the Evaluation Result

Finally, students critically discuss the results and methods of their first experience of data-based decision making. Questions that can help in this critical discussion include the following: (1) Which value model is best suited to the model of sustainable development? (2) How could the value model be modified in order to gear decisions more closely to the model of sustainable development? (3) Which value model represents the common values and norms of the class (or society)? (4) Which indicators were not taken into account? (5) Which evaluation criteria did the different roles use? (6) How and why do the results differ from an "intuitive evaluation," such as the one conducted at the beginning of the teaching unit? And (7) should the model be modified to improve the outcome – why or why not? (cf. Bögeholz, 2006, p. 21).

In a final discussion, the method of data-based decision making should be criticized, with the active involvement of the students. The main point of criticism is the (nonexistent) numerical accuracy of the procedure. According to Bögeholz (2006), the numerical values never represent absolute values of the selection options but are instead "exclusively in the service of selecting courses of action" (p. 21). The advantage of these – in comparison to alternative evaluation methods such as purely intuitive decision making, which takes place without any visualization of selection criteria – lies in the perception of the decision criteria and the decision process. On one hand, students can realize how diverse and complicated decision-making processes can be, especially in socio-scientific discourses, while, on the other hand, they learn a way to structure their decision-making processes in a meaningful and transparent way.

○ Teaching the Topic of "Edible Insects" in Biology Class

This lesson is intended for grades 9–12 and will require a total of four to six hours. As an introduction to this teaching unit, students can be presented first with a picture of an insect burger and then with the corresponding raw ingredient, buffalo worms (*Alphitobius diaperinus*; Figure 3). At the same time, the students should be asked whether they would eat the burger after the presentation of knowledge that the buffalo worms are a basic ingredient of the burger patty. This impulsive feedback initiates a first-class

Figure 4. Useful starter videos for conducting internet research on entomophagy.

discussion and should, if possible, lead to a vote for or against the consumption of insects. In this way, students make an initial intuitive decision at the beginning of the lesson – which can be picked up and contrasted again at the end of the lesson, after the experience of data-based decision making. The following (or a similar question) should be noted on the blackboard as a central problem question for the further course of the lesson: "Why should we use insects as food when we can eat meat?"

Next, the students receive a newspaper article comparing the health and sustainability aspects of the consumption of insects and meat (Figure 5). The material in this article is intended to provide students with initial input for the subsequent identification of work priorities that appear necessary for dealing with the problem question and for decision making (e.g., sustainability of insect or meat production, population growth and animal protein sources, nutrient composition). Further, students should be given the opportunity to carry out their own internet research on the focal points of their work (Figure 4).

In the subsequent development phase, the students are asked to work in "research groups" of about four people to review the identified focal points of the work. This phase is intended to provide students a knowledge foundation for selecting evaluation criteria for data-based decision-making. "Hard criteria" such as CO_2 emissions or energy use in the production of meat and insects might be used, but "soft criteria" such as the (expected) taste of insects and meat could also be considered. This is followed by the practice of data-based decision making in the last teaching phase, using Table 2.

Figure 5. Fictitious newspaper article to be used as teaching material.

To solidify the learning they achieve through this decision-making exercise, students should present a real-life example of how they have begun to apply the lesson to their everyday life – both just after the exercise is completed and at the end of the semester or school year. This will not only help them sustain the new decision-making behavior but also illustrate the difficulty or success of maintaining a new decision-making process and behavior.

All figures and tables for this article are available as supplemental material for download with the online version of this article.

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