Integrating Probability Modeling Concepts in Secondary Education

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Abstract

This paper highlights recent developments in the creation and implementation of educational modules for the instruction of probability modeling and simulation in secondary education. Each module consists of a collaboratively produced self-contained DVD that describes real-world applications of probability concepts. When implemented in a problem solving group setting, the modules create a knowledge-based environment for student learning, as is described in the How People Learn research compilation of the National Research Council. The concepts that are learned through the modules coincide with those set forth by the National Council of Teachers of Mathematics for 9-12 year secondary education students, which include 1. the use of simulation to construct empirical probability distributions, 2. the key role of certain descriptive statistics to describe the shape of a distribution, and 3. the calculation of regression coefficients for statistical predictions of future system behavior.

The modules are integrated into the curriculum of high school probability and statistics courses, including the Advanced Placement Statistics course. The number of schools offering this course has been rising rapidly in number since the introduction of the Advanced Placement program in the early 1990's. A module whose topic involves the population dynamics of the Africanized honeybee infestation is described in this paper. This module is presently being implemented in several schools in Texas in a test-bed setting, and supplemental instructor aids are currently under development. To view and request samples of the modules, please visit the website http://engr.nmsu.edu/~csm/nsf-project. This material is based upon work supported by the National Science Foundation under Grant No. 0230643.

Module Development

There have been numerous recent educational research publications that suggest the need to introduce the concept of "statistical thinking" into secondary education programs, i.e. focus the curriculum on teaching students to think about contextual problems from a statistical viewpoint (Wild and Pfannkuch [1], Pfannkuch and Wild [2], Moore [3]). In response, there are a number of new textbooks and enrichment materials targeted for the Advanced Placement Statistics curriculum, which develop the role of statistical thinking in addressing problems of practical interest. Other recent publications, such as the NCTM Navigation through Data Analysis series [4], provide materials and activities for students to learn statistical thinking by 'interrogating' data. The educational modules presented in this paper supplement these other materials by introducing the field of probability modeling and simulation for students' statistical thinking. In order to engage the students, each module presents an application of a current scientific problem of interest that is presented by a multifaceted team of experts through visual media. The subsequent analysis by the students helps them conceptualize the specific NCTM Data Analysis and Probability standards that have been prescribed for grades 9-12. The overall educational objectives of the modules are 1. a more comprehensive level of knowledge development in secondary probability and statistics courses , 2. the development of an ability by the students to transfer key probability concepts from one scenario to another, and 3. an increased number of high school students pursuing science and engineering degrees.

The pedagogy behind these modules is based on concepts recently published by the National Research Council in the research compilation How People Learn [5]. In particular, the modules create a knowledge-centered learning environment for student learning, which builds upon the prior knowledge that an individual possesses about a particular problem through an iterative process of multi-step corrective refinement. As this process progresses, erroneous concepts are replaced with correct ones towards the ultimate conversion of learned information to useful knowledge. A contrasting curricular approach, which is common in many secondary programs, is to simply present new information to the students through lectures and trivial examples. The latter approach, however, relies on the self-conceptualization of presented information by the students, and has been shown to be less effective in developing student problem solving skills and knowledge transfer aptitude. In an overall sense, the knowledge-centered environment starts with what the student knows rather than what the instructor knows. The associated learning theory is that it is more effective to focus on shaping perceived student concepts than it is to expect them to completely absorb new ones.

The educational modules presented in this paper create a context upon which students may organize their knowledge of probability. As new information is discovered through lecture or their own studies, the students will place this information in these established contexts. At the end of each module, the students are given the challenge of solving the problem as a team. The team members present ideas and concepts to one another in preliminary discussions about how to solve the problem. This may include information about the application and concepts of probability. The team will collectively decide upon an initial model based on these discussions, which will be subsequently statistically tested and solved for a particular instance. As this series

of actions is performed, concepts that are erroneous will become apparent either through group observation or instructor guidance. The teams will start the process again with a new or modified model until one that is acceptable is found. The base of knowledge for each team member will be updated and corrected as this iterative process progresses. The usefulness of the module as a learning tool extends beyond this exercise, however, as new information acquired over time will be continually placed back in this context further adding to the knowledge base.

To avoid the potentially damaging effects of overcontextualization, i.e. ultimately contextualizing rather than conceptualizing the subject of probability, and to promote learning transfer, each module contains an 'extension' section in which the students are asked to use the concepts learned to solve a related problem from a different field of application. The extension problem is not fully described as is the topic problem, but rather only described through a brief (<5 min) video and a set of data. As an example, if the topic of the module was the analysis of the equilibrium size distribution for an ecological population, an extension may be to find the equilibrium distribution of a flow line in a manufacturing problem. Hence, the students must transfer the base of knowledge that was developed when solving the main problem to the solution of this extension problem.

Module Description

A description of the module whose topic involves the population dynamics of the Africanized honeybee infestation is given in this section. This module is complete at the present time and is one of three modules of planned production. As previously noted, this module is self-contained with all necessary videos, related papers, and data sets. The DVD comes packaged with attractive cover art, given in figure 1, which portrays a sense of professionalism in the work in which that the students will be engaged.

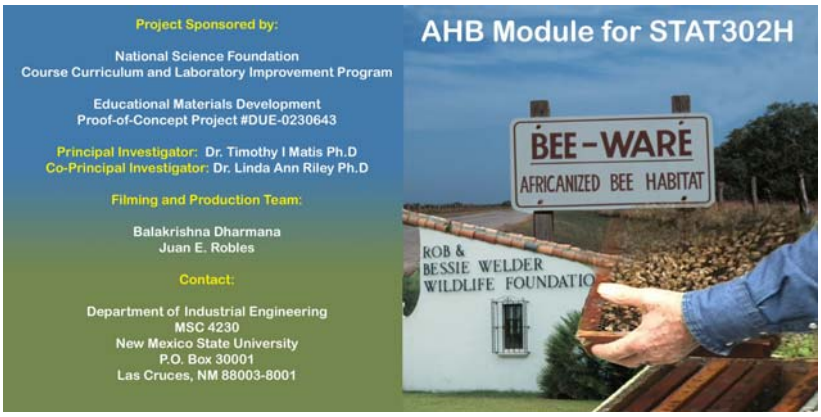

Figure 1: DVD Cover Art

The migration of the Africanized honeybee (AHB) that started with accidental release in South America in the early 1950's is said to be one of the greatest ecological events of this century. The Africanized bee, which is characterized by its defensive behavior, displaced the gentler European honeybee along its migratory path through Mexico into the western United States in the early 1990's. Neither the pace or direction of this migration were controllable

through human intervention. Climatic changes and the infestation of the varroa mite, a natural enemy, were the only forces that seemingly affected the rate of infestation and population size of the Africanized bee. The media attention that was generated surrounding this event, including factual stories, Hollywood movies, and the coining of the term "Killer Bee", created a heighten sense of public interest in this subject. It is interesting, if not fascinating, for many students to learn of this event, study the impact it had on feral and managed populations, and develop probability models of the equilibrium distribution of the Africanized honeybee in different areas.

Each module consists of a self contained DVD with several movies of experts in this field describing various aspects of the problem in their "home" settings (Figure 2).

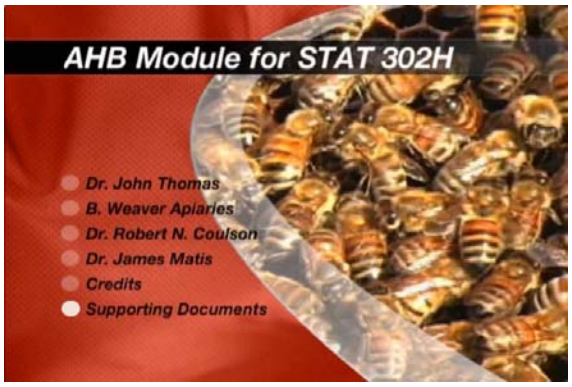

Figure 2: Introductory Screen of the AHB module

The Africanized honeybee module is divided into five main video sections, specifically 1. an introduction to the problem by John Thomas, a retired extension entomologist at Texas A&M University (Figure 3), 2. the effect on feral population at the Welder Wildlife Reserve by Robert Coulson of the Department of Entomology at Texas A&M University (Figure 4), 3. the effect on managed honeybee colonies by Binford Weaver of B. Weaver Apiaries (Figure 5), 4. scientific aspects of the problem by James Matis of the Department of Statistics at Texas A&M University (Figure 6), and 5. extension to the population dynamics of badgers and foxes by James Matis.

Figure 3: John Thomas

Figure 4: William Coulson

Figure 5: Binford Weaver

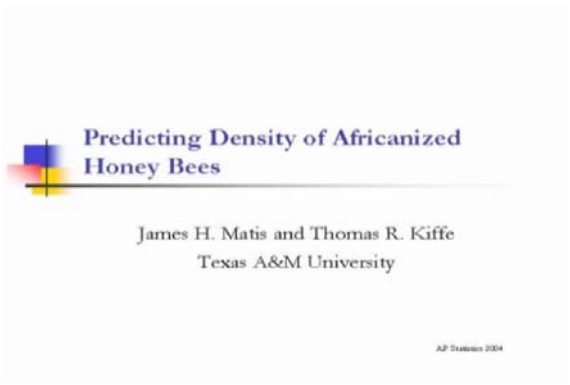

Figure 6: Power Point Slide of James Matis

Each presenter is an expert with numerous years of experience in the material that they are presenting. These videos have undergone extensive editing for length and content, and have been augmented with numerous textual and graphical overlays (Figures 7 and 8).


Figure 7: Graphical Overlay

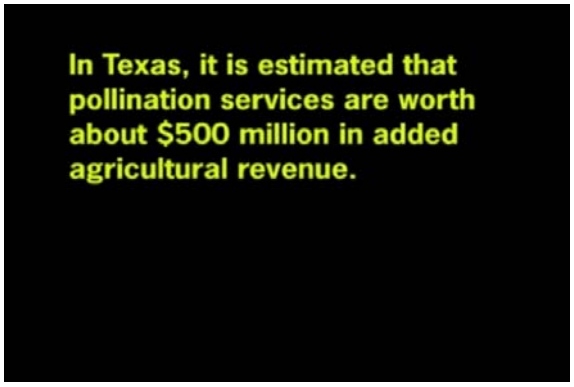

Figure 8: Textual Overlay

The DVD contains additional sections which have downloadable papers, presentation, and data sets that support the problem.

Some of the general scientific problems concerning the African bee were presented to students at a south Texas high school in week-long summer workshops during three different occasions. The underlying pedagogical approach described in this paper was implemented by dividing the students into teams, with each team charged to produce a written and an oral report of their findings. The results from this RAPS (Research for AP Students) program were very encouraging. The scientific problem was subsequently selected for inclusion in a book containing model statistical applications appropriate for AP students [6], and the students were instrumental in developing and testing methodology for using saddlepoint approximations for bee-related probability distributions [7]. The DVD module was created to disseminate this very successful program to a much larger population.

The AHB module should be presented to a team of students following introductory lectures on probability. The specific problem that is presented by this module is to generate an

equilibrium size distribution for the population of Africanized honeybees on the Welder Wildlife Refuge. This involves using the given data to parameterize population-dependent birth and death rate functions. Each team member should be given time to view the videos independently and formulate initial thoughts on the problem solution. The team of students will then meet on multiple occasions to discuss these ideas and formulate a plan for solving the problem. The instructor of the course should be present at these meeting to ensure that the team is functioning properly, but should avoid directing the solution approach of the group as the errors in problem formulation will be self-discovered as the work progresses. The solution to this problem may involve simulation, for which a primer on using crude random number generation to simulate systems by hand is included in the video by Dr. James Matis. As an assessment mechanism, the instructor could ask the groups to turn in a report and/or give an oral presentation of their findings. Upon successfully completing this problem, the instructor may assign the student the extension video on badgers and foxes, whereupon the solution process repeats itself. On the extension problem, however, the students are expected to gather information through written materials which are included on the DVD to understand and gain insights into the problem.

Implementation and Assessment

The educational modules may be implemented in any probability and statistics course that is taught at the secondary education level. The particular course that is part of the Advanced Placement program may find that the modules work well in the latter part of the course, typically after completion of AP exam preparation. The solid pedagogy and exposure to advanced topics that is provided by the modules serve to defray some of the recent national criticisms of the AP program [8,9], that being a lack of collegiate equity due to insufficient rigor and depth. Copies of the modules together with any available support material will be sent upon written request. To facilitate the seamless integration of the modules and overcome the barriers of subject unfamiliarity, we are planning to 1. integrate the modules into the Advanced Placement Summer Institute workshops held annually at Texas A&M, and 2. organize workshops at NCTM conferences that highlight module usage.

The modules are presently being implemented in several schools in South Texas for assessment purposes. Assessment data is not yet available from this implementation, yet preliminary feedback from the course instructors is highly optimistic.

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