Science is Zarked: An Intelligent Tutoring System for Learning Research Methods

Samantha F. Warta
University of Central Florida Institute for Simulation and Training
swarta@stetson.edu

INTRODUCTION

Intelligent tutoring systems (ITSs) have two primary goals: a) specifying *what* concepts to teach an individual learner and b) *how* to teach them through personalized instructional strategies (Ohlsson, 1987; Wenger, 1987). Science is Zarked is an ITS, designed and validated with the Generalized Intelligent Framework for Tutoring system (GIFT; Sottilare, Brawner, Goldberg, & Holden, 2012), for teaching a basic course on research methods. The motivation for constructing this ITS stems from the need to address a low-level training gap within university-associated labs. That is, no accredited system intended to train and evaluate students on their level of research methods knowledge currently exists. Specifically, this ITS is targeted at students applying for positions as undergraduate research assistants in university-associated labs. As such, redressing this training gap is essential and through the creation of Science is Zarked, university-associated labs will save both time and money.

While teaching aspects of the scientific method and various research techniques applicable to most scientific disciplines, this tutor aims to use other ITSs dedicated to science education as the foundation for designing a system targeted at learners with very little knowledge about science or research methods. To that end, Science is Zarked is grounded in a pedagogy-oriented approach to aid exploration of the programmatic learning content structure of this ITS. That is, this ITS focuses on the sequence of the material taught and the strategies used to teach the content. Specifically, this system employs pedagogical strategies such as: (a) an adaptive courseflow, to adjust to individual learner characteristics – such as, existing knowledge, desire for feedback, and performance – in an effort to positively influence learning outcomes; (b) a programmatic content structure, which emphasizes the retention of concepts through gradual introduction and repetition to enable learners to develop a genuine understanding of scientific research; and (c) the case method of instruction, to bridge the gap between theory and application. In addition to gaining greater understanding of how these teaching strategies influence learning outcomes, the primary goal of this ITS is to encourage learners' interest in the sciences and demonstrate the ease of mastery of relatively basic scientific concepts.

As such, the first section of this paper will examine literature related to GIFT and ITSs for science education. The second section will introduce Science is Zarked, the ITS central to this paper, and further describe the problem it was intended to address. Additionally, this section will review design decisions and provide an in-depth examination of the system's structural components as well as detail the pedagogical strategies employed. As a final point, this paper concludes with a review of the lessons learned, recommendations for GIFT features to provide further functionality in this domain, and future plans for Science is Zarked.

GIFT

GIFT, the Generalized Intelligent Framework for Tutoring (Sottilare et al., 2012), is a system intended to aid in the design and generation of computer-based tutoring systems. Developed under the Adaptive Tutoring Research Science & Technology project, GIFT represents a system grounded in empirical study. The development of this framework of tools is supported by researchers at the Learning in Intelligent

Tutoring Environments (LITE) Laboratory, part of the U.S. Army Research Laboratory – Human Research and Engineering Directorate (ARL-HRED) and was designed to facilitate study of computer-based tutoring systems throughout the government, industry, and academia (ARL GIFT, 2016).

Relevant to this discussion is Murray's (1999) classification of ITS authoring tools, as either pedagogy or performance-oriented, in accordance with each system's capabilities (see Figure 1 for a visual representation of this conceptual mapping). Pedagogy-oriented systems primarily emphasize the teaching and sequencing of content. On the other hand, performance-oriented systems are most concerned about learning outcomes, focusing on teaching learners by allowing them to practice learned skills while receiving feedback. However, GIFT does not fall into only one of these categories as it enables the design of an ITS with pedagogy and/or performance-oriented features. Accordingly, four modules characterize GIFT's capabilities: the sensor, learner, pedagogical, and domain modules. The sensor module enables the monitoring of individuals through commercial sensors and provides an interface to GIFT while formatting, processing, and storing the collected data. The domain module is concerned with providing domain-specific content, assessment, and feedback. However, the domain module only provides feedback when the pedagogical module determines it is necessary. Lastly, the learner module assesses an individual's cognitive and affective state through the tracking of performance, historical, and sensor data.

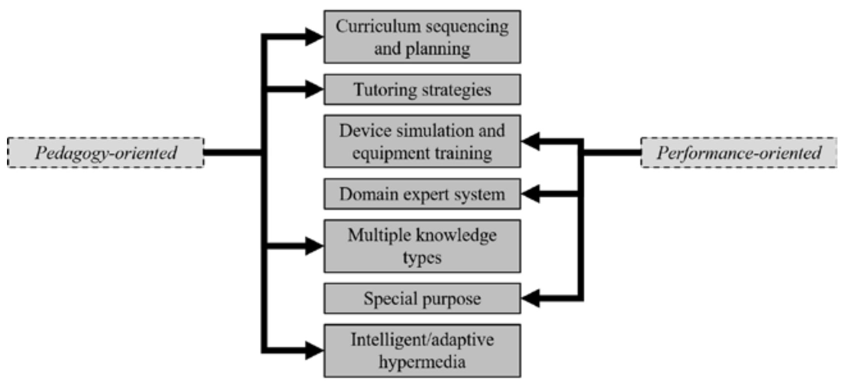

Figure 1. Conceptual Mapping of Murray's (1999) ITS Capability Classifications.

Intelligent Tutoring Systems for Science Education

A brief review of the literature yielded three ITSs designed specifically for varying facets of scientific education. These tutors consist of My Science Tutor (Ward et al., 2013), the Modeling and Inquiry Learning Application (Joyner & Goel, 2015), and the Andes system (Vanlehn et al., 2005). All three systems provide valuable insight into the teaching of science-related concepts and a useful comparison to Science is Zarked, as well as inspiration to guide the development of future GIFT capabilities to support ITSs in this domain.

My Science Tutor (MyST; Ward et al., 2013) is an ITS that teaches scientific concepts targeting elementary school students. Using an avatar named Marni, MyST is designed to employ conversational dialogues supplemented by illustrations, animations, and interactive simulations to teach learners scientific concepts. Ward et al. (2013) split learners into three groups: a classroom of learners taught under normal conditions by a single teacher to serve as a control, one on one tutoring with a human tutor, and one on one tutoring with a virtual tutor. Results indicated that both of the one on one tutoring groups had significantly higher learning gains than the control groups. However, there was no significant difference in learning gains between the two tutoring groups. Thus, evidence supported the assertion that expert human tutoring is equivalent to virtual tutoring in the case of MyST.

The Modeling and Inquiry Learning Application (MILA; Joyner & Goel, 2015) represents another example of a system designed for science education. MILA is a metacognitive tutoring system that uses inquiry-driven modeling to teach various scientific concepts. Using this system, learners create a model to describe a phenomenon while MILA-Tutoring (MILA-T), an intelligent agent, monitors and responds to learners' behavior. MILA-T represents a pedagogical agent, divided into five different versions: a Guide, a Critic, a Mentor, an Interviewer, and an Observer. The Guide and the Critic do not provide feedback unless asked whereas the Mentor, Interviewer, and Observer interrupt a learner's actions when appropriate. However, the Observer primarily operates in the background by feeding information to the other agents. Joyner and Goel (2015) used five classes of learners, placing two into a control group and three into an experimental group. The control group utilized MILA while the experimental group used MILA with the addition of MILA-T. Comparing interaction logs between the control and experimental groups, Joyner and Goel examined how MILA-T influenced learners' modeling and inquiry processes. They provided evidence to support the assertion that learners' engagement was greater with the MILA-T addition. Specifically, their results suggested that learners utilized the feedback and retained the information received from the tutoring system. Learners were most likely to revise their models and expound upon them after tutor interactions. Thus, MILA-T not only improved learners' engagement by positively influencing their disposition, but also improved their performance on modeling and inquiry tasks.

The Andes system (Vanlehn et al., 2005) is an intelligent physics tutoring system designed to improve learner performance through interaction. Studied at the United States Naval Academy, Andes significantly improved student learning. According to Vanlehn et al. (2005), the key to Andes' success was the form of answers elicited from learners, representing a "whole derivation, which may consist of many steps, such as drawing vectors, drawing coordinate systems, defining variables and writing equations" (p. 147). Here, the focus is not on the content, but rather the method with which it is taught.

SCIENCE IS ZARKED

Science is Zarked is an ITS designed to teach a basic course on research methods through the GIFT authoring system (https://cloud.gifttutoring.org/). In addition to teaching aspects of the scientific method and various research techniques, this tutor also aims to provide the best practices related to each research method. While the content within this tutor was not meant to be representative of an introductory level research methods course that spans an entire school semester, it offers enough content to provide a broad perspective relating to several different experimental designs and research methods utilized in various scientific disciplines. The current version of Science is Zarked can be accessed at the following URL: https://cloud.gifttutoring.org/tutor/?eid=a4b87263-e3bd-47d3-a0be-b1bd0fda3980.

Rationale and Benefits

Employees in university-associated labs regularly hire undergraduate students to assist with various tasks on projects, like experimental design and data collection. Usually the students hired have little to no experience in a scientific research setting and arrive with nothing more than the knowledge retained from basic high school science courses. The problem here is that to successfully and effectively collect data during an experiment, some knowledge of scientific research methods, beyond what students learned in high school, is required. However, there is currently no accredited system that ensures students have at least a basic understanding of research methods, so lab employees must train each individual student they hire every semester. This has the potential to be both a time consuming and labor-intensive process, depending on the individual student. Thus, the creation of an ITS designed to teach these basic research methods concepts will be beneficial to labs by enabling them to save time and money when training new undergraduate research assistants.

Design and Structure

As mentioned previously, specific pedagogical strategies utilized by Science is Zarked include: (a) an adaptive courseflow, (b) a programmatic content structure, and (c) the case method of instruction. Overall, this ITS seeks to provide a solid coverage of the basic concepts presented to learners during an introductory research methods course, offering supportive material and organizing the modules to enhance student learning outcomes. This ITS's design emphasizes the retention of research concepts through gradual introduction to terms and demonstration of their application through case studies. In particular, this enables learners to develop an understanding of scientific research as an interconnected and integrated process of thinking rather than a series of disembodied concepts. While merely an introduction to various research methods and experimental approaches, this ITS underscores the importance of empirical research, and the methods detailed within, to build upon current scientific knowledge. See Figure 2 below for an overview of the structure of the tutor.

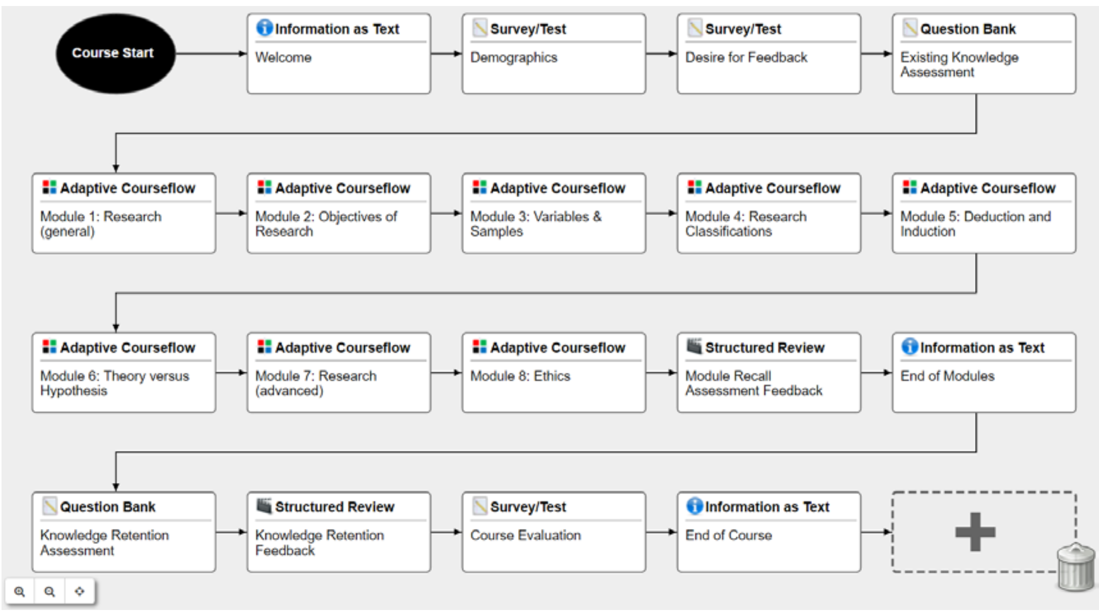

Figure 2. Structure of the Science is Zarked Intelligent Tutoring System.

Course Concepts

Comprised of eight different modules, Science is Zarked is structured such that a student with very little knowledge about science or research methods within any scientific discipline is capable of comprehending and gaining applicable knowledge as well as insight from the course materials. Likewise, a more experienced student, that may have taken a course or two in research methods, also shares the possibility of learning something new. The general layout of this tutoring system begins with a module that provides an introduction to scientific research and empirical research methods. This first module teaches the learner what research is and what it is not by providing material on several relevant concepts and terms. Additionally, this module outlines the scientific method and makes an effort toward outlining the qualities of good research. The modules that follow build upon one another and become increasingly more complex, covering topics ranging from the objectives of research, deductive and inductive reasoning, the difference between hypotheses and theories, comparing the various systems of research; to addressing more advanced topics like ethics in research as well as characteristics of samples and variables, reliability, and validity. See Table 1 for a full listing of the modules and each concept they cover. Items for the recall assessments in these modules were generated based upon previously taken research methods courses, reviewing the literature to attain content validity, and modified from several web-based sources (Dattalo, n.d.; Marley, 2007). Future updates to Science is Zarked, a GIFT course export file, and the material presented in the learning phase and recall assessment for each module can be downloaded from https://www.researchgate.net/profile/Samantha_Warta.

Table 1. Science is Zarked Modules and Concepts Covered.

Module	Name	Concepts Covered
1	Research (general)	Basic concepts and terms, what is research?, qualities of good research, the scientific method
2	Objectives of Research	Descriptive, correlational, explanatory, and exploratory research
3	Variables and Samples	Independent and dependent variables; the importance of operationalization; continuous, non-continuous, and extraneous variables; samples; random and non-random sampling; characteristics of good samples; sample biases
4	Research Classifications	Basic and applied research, quantitative and qualitative research, experimental and non-experimental research
5	Deduction and Induction	Deductive and inductive reasoning
6	Theory versus Hypothesis	Hypotheses, characteristics of a good hypothesis, theories, characteristics of a good theory
7	Research (advanced)	Rule of parsimony, replication, reliability, and validity
8	Ethics	Ethics in research, use of the institutional review board, informed consent, harm and risk, deception

Pedagogical Features

Adaptive Courseflow

ITSs that are adaptive in nature offer learners a uniquely tailored learning experience based on the individual needs of a particular student. Three learner attributes that are important for a tutoring system to take into account are learner knowledge (Gertner & VanLehn, 2000), learner cognitive skills (Arroyo et al., 2004; Royer et al., 1999), and learner attitudes (Arroyo & Woolf, 2005). Assessing existing learner knowledge provides students with an ITS that both benefits learning outcomes and is capable of a wide range of teaching techniques, while discerning the optimal teaching intervention (Gertner & VanLehn, 2000). Previous research has shown that pre-existing knowledge influences performance within ITSs (Taub et al., 2014; Trevors, Duffy, & Azevedo, 2014). Accordingly, Science is Zarked begins by assessing existing learner knowledge through administration of a pre-test on the concepts covered by all course modules. The primary objective of this pre-test is to feed data, pertaining to each individual learner, into the ITS to establish their existing knowledge base and influence the course flow. As GIFT capabilities permit, this will mean providing learners with the option to skip the learning phases within modules in which they have demonstrated mastery of a given concept by correctly answering all question items associated with that module during the pre-test.

Collecting information pertaining to a learner’s cognitive skills and adapting a tutor based on this has the added benefit of improving learning outcomes (Arroyo et al., 2004; Royer et al., 1999). Since cognitive skills can be reasonably characterized by processes governing thinking, attention, learning, memory, and reasoning, then a simple measure of an individual’s cognitive skills can be gathered by inquiring about the highest level of education achieved (Ceci, 1991). Within the demographics survey object, learners answer questions relating to not only their highest level of education achieved, but also their major or focus of study and their science course history. This establishes an additional measure that functions as another check on the existing knowledge assessment and support determination of level of expertise.

Following this, the ITS transitions into an assessment designed to measure an individual's desire for feedback (Moore, Erichsen, & Warta, 2014). According to Renkl (2002) and Wood and Wood (1999), a connection exists between learners' behavior, attitudes, and perception. For example, when students interacted with an ITS and it provided meaningful feedback, this positively influenced the learning outcome by affecting attitudes (Aleven et al., 2003; Arroyo & Woolf, 2005). Given the connection between perception, behavior, and attitudes, it is crucial that the learner's willingness to receive feedback be measured such that an ITS adapts appropriately. As a result, the pedagogical module within GIFT was set to recognize when learners scored high or low on the desire for feedback measure and will, accordingly, offer hints and question-by-question feedback as learners complete the recall assessment in each adaptive courseflow module.

After these surveys, eight adaptive courseflow modules teach learners a series of scientific concepts. Within these modules, the ITS presents course content to learners before they answer questions on a recall task. If learners do not score sufficiently high enough (i.e., answer approximately 80% of the questions correctly), then they are unable to advance to the next module and must repeat the current module's learning phase until they receive an acceptable recall score. However, while the intent is for learners to be able to skip the learning phases of these adaptive courseflow modules as a function of their scores on the existing knowledge assessment, they will still be required to complete the recall questions during the assessment phase. This serves as a secondary check on learners' existing knowledge to ensure that they truly understand the concepts taught in each module and did not just happen to guess the correct answer on the existing knowledge assessment.

Once learners have completed all eight modules, they are able to access a structured review, which provides the learner with a summary of all the assessments taken throughout the course as well as any feedback offered. Next, learners complete a knowledge retention assessment in the form of a post-test of the existing knowledge question bank. Scores from the knowledge retention assessment can then be compared to the existing knowledge assessment scores in a pre-test/post-test analysis. This will measure learner improvement or decline and ensure the effectiveness of the learning phase content in teaching through the three primary pedagogical strategies employed. Lastly, learners complete a course evaluation designed to assess the functionality of the course content and identify where the course has the potential for improvement. The course evaluation consists of subjective self-report answers and provides a useful comparison to the more objective measurement of learner performance throughout the course. Items for this measure were modified from the Berkley Center for Teaching & Learning course evaluations question bank (UC Berkley, 2016). This course evaluation asks learners to rate the clarity of the course content presented as well as its usefulness in completing each module assessment. Additionally, the course evaluation will serve as a "manipulation check" of sorts in that it will not only assess the effectiveness of the feedback provided to learners, according to their score on the desire for feedback items, but also their satisfaction with the course. In particular, this will serve to reinforce the validity of the desire for feedback measure and its inclusion as an adaptive component for Science is Zarked.

Programmatic Content

The structure of the learning content within Science is Zarked is best characterized as programmatic in nature. That is, difficult or unfamiliar concepts are introduced within the beginning modules to the extent that it facilitates this introductory discussion. Later modules then reexamine these concepts to provide a fuller picture. As learners progressively work through each module, the addition of new concepts to those already introduced provides a more coherent model of the empirical research process. Beginning at a very basic level, this ITS allows learners to progressively master the ideas presented, working their way up to more complex and comprehensive concepts. This design provides a rational and comprehensible experience of a very basic set of research methods by forcing each module to build upon the previous module rather than presenting learners with multiple, individual and independent, disembodied ideas. While this structure may seem rather repetitive in nature, and indeed allows for an adaptive courseflow that enables learners to repeat content, such repetition is actually useful to building knowledge that is more easily accessible on recall (DeKeyser, 2007; Kuczaj, 1983; Larsen-Freeman, 2012; Rydland & Aukrust, 2005; Weir, 1962). As mentioned in the previous section, the success or failure of such repetition throughout the course is easily verified in a pre-test/post-test analysis using the existing knowledge and knowledge retention scores.

Further, another element of the programmatic content within this ITS includes the use of graphical visualizations and simulations alongside the written material found within the learning phase of each module. While MyST could be reasonably classified as a performance-oriented system, Science is Zarked represents a pedagogy-oriented system much like MILA and Andes. That is, this ITS was designed to adapt to individual learners and focus on the sequence of the material taught as well as the strategies used to teach the content. In particular, throughout the course modules, Science is Zarked utilizes several graphical representations to illustrate scientific concepts, mirroring MyST's use of this media (see Figure 3).

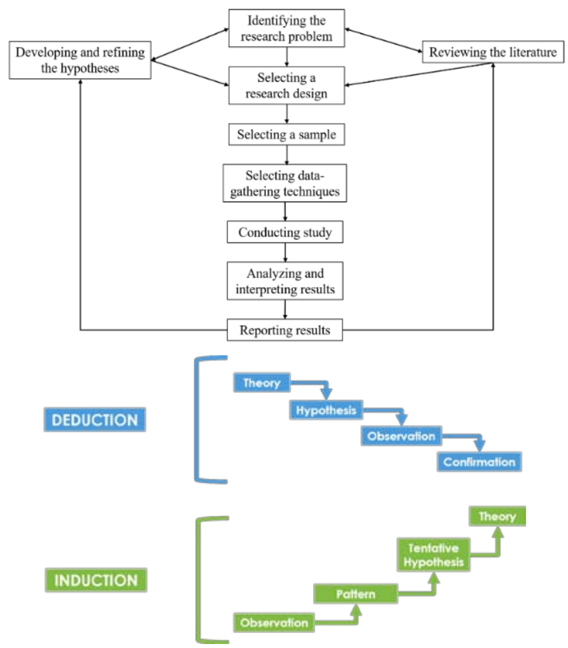

Figure 3. Visualizations used in Science is Zarked. *Top:* Steps of the Scientific Method (adapted from Blum & Blum, 2013). *Bottom:* Comparison of Deduction and Induction Approaches.

Then, following the module on *Variables and Samples in Scientific Research*, the ITS redirects learners to a natural selection simulation (Saul, 2005). This serves both as a fun activity and reinforces the content pertaining to the previous module. The simulation directs learners to manipulate the independent variable (mutation levels of the organisms) to see how it influences the sample. This type of simulation provides content similar to that found in MILA and the Andes system. Additionally, this type of content increases learner engagement with the material, utilizing the repetition and application of concepts to improve recall.

Case Method of Instruction

Similar to MyST, MILA, and the Andes system, one of the central teaching methods Science is Zarked utilizes is case studies (see Figure 4). In the lesson content within each module, short case studies help illustrate a particular concept, teaching application in addition to the strictly theoretical nature of the remaining lesson content. This strategy of teaching is crucial to developing learners' ability to apply theoretical knowledge to complex situations they may encounter. Also known as the case method of instruction, this approach was specifically designed to bridge the gap between theory and application (Jackson, 1985; Johnson & Purvis, 1987; Kleinfeld, 1990; Lee, 1983; Newey, 1987; Rasinski, 1989; Schwartz, Fiddes, & Dempster, 1987; Scully, 1984).

To test the hypothesis, "Listening to music lowers blood pressure levels", there are two ways of conducting research:

- **Experimental (helps determine causation):** Participants are divided into two groups. One group listens to music while the other does not. Compare blood pressure levels.
- **Correlational (does not determine causation):** Using a survey, ask participants how they feel in addition to how often they listen to music, and then compare the results.

Figure 4. Case Study used to Illustrate the Differences Between an Experimental and Correlational Design.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The ITS development process in GIFT was not well-defined and challenging at times, since examples of successful systems built using GIFT were limited. During initial design of Science is Zarked, other scientific education ITSs acted as models to support the inclusion of validated teaching techniques and information elicitation methods. However, while GIFT excels in other areas, the options for eliciting information from learners and providing an interactive environment conducive to teaching scientific concepts were sparse. Approaches to collecting information from learners on surveys in GIFT were limited to multiple-choice questions, slider bars, and rating scales. Specifically, capabilities like those seen in MILA's interactive model-building interface or the ability to draw, define variables, or write equations like in the Andes system, would be useful in ITSs for science education. An interactive interface is requisite for modeling hypotheses and "running" a simulated experiment within the system to demonstrate different types of research methods or experimental effects, for instance. Alternatively, assessment items within an ITS could ask learners to arrange the procedural steps of the induction and deduction approaches, found in Figure 3, in the correct order. While these particular capabilities have been described herein to benefit an ITS focused on science education, they also have potential application in other domains as well.

Future plans for Science is Zarked include testing the efficacy of the ITS in its current form as well as adding an assessment of learners' attitudes at the mid-point of the course, so that it may adapt from that stage for the purpose of providing learners with a provisional and adjustable frequency of feedback. The addition of supplemental modules to those already covered are planned to include: a) specific experimental designs (e.g., between-subjects and within-subjects designs), b) experimental effects (e.g., practice effects, carry-over, etc.), and c) an introduction to basic experimental statistics. In effort to retain relevance and offer greater customization of this ITS to university-associated labs, additional modules could be added to cover special topics that are relevant to the existing projects for which a lab may currently be training undergraduate research assistants. Further planned improvements for this ITS also includes an addition of supplemental items to the module recall assessments for adaptive purposes, so that the difficulty level can be further tailored to each individual learner.

To conclude, Science is Zarked represents a novel contribution to the ITS community given that reviews of the literature did not reveal any other tutor, authored with GIFT or another system, addressing research methods. The purpose of this paper was to lay out the preliminary design of this ITS and importantly, demonstrate the applicability of GIFT as an essential tool in the design of ITSs focused on science education.

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ABOUT THE AUTHOR

Samantha F. Warta, M.S. *is currently working as a research assistant in the Cognitive Sciences Lab at the University of Central Florida's Institute for Simulation and Training. Recently, she graduated summa cum laude with her Master's of Science in Modeling and Simulation from the College of Engineering and Computer Science at the University of Central Florida. Samantha received her B.A. in Psychology with a minor in Applied Statistics from Stetson University. She has previously published papers in the areas of college students' volunteering, serious games, human-robot interaction, and artificial social-cognitive architectures. Her current work includes the continued development and validation of a robotic perception scale, mental state attribution for effective social human-robot interactions, and the design of a novel robotic sensor system for the perception of social cues and signals.*