Holistic Development of Undergraduate Students – Concept Cartoons to Authentic Discovery

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ABSTRACT

This paper describes a holistic pedagogical approach for classroom engagement. The project translates theory and fundamental classroom knowledge to authentic application with cutting edge research implemented by undergraduates at a Historically Black University. In our project, we developed and assessed cartoons custom designed for classroom instruction and evaluated student engagement while using the cartoons. We further report on student successes achieved through undergraduate research projects.

Keywords: custom cartoons, student engagement, undergraduate research

INTRODUCTION

This paper discusses the first year results of the Targeted Infusion Project (UMES-TIP) at the University of Maryland Eastern Shore (UMES) funded by the National Science Foundation (NSF). There are five aspects to the UMES-TIP project to be evaluated, but only two aspects served as the evaluative focus in the first year of implementation during the 2017-2018 academic year. First, the project developed and cartoons custom designed for the project, assessed student views regarding the cartoons and evaluated student engagement with the cartoons. Second, the project looked at the first year success of an undergraduate research requirement.

If the United States is to retain its historical prominence in science and technology, this nation must produce more science, technology, engineering and mathematics (STEM) graduates. Towards this end, the President's Council of Advisors on Science and Technology has called for a 33% increase in STEM majors per year (1). Unfortunately, of the approximately 300,000 students who enter college annually to pursue STEM majors, only 40% complete a STEM degree. Moreover, we need the increased participation of underrepresented populations (e.g. blacks and Latinos) in STEM fields as they are less likely to pursue STEM degrees than their majority counterparts.

The UMES-TIP grant enables UMES to respond to these urgent STEM needs by introducing innovative teaching methods tailored to the needs of Historically Black Colleges and Universities (HBCU) students to advance a rigorous, state-of-the-art STEM curriculum in physics. The UMES-TIP project targets student engagement in physics. The goals of the project are to improve student learning in physics and to increase student retention. Supporting these goals are five objectives: 1) increase student interactions through group learning, 2) better align labs and lecture content, 3) develop physics cartoons which elucidate key physics concepts, 4) utilize physics cartoons with classroom clickers and 5) implement a senior year research project. This paper discusses the first year results addressing objectives three and five.

Background and Context

UMES is a historically black university and the 1890 Land Grant Institution for the State of Maryland, centrally located on the Delmarva Peninsula. It accepts approximately half of the undergraduate applicants each year. In the fall of 2015, the median SAT score of all entering first-time undergraduates was 861 (50%=840, 75%=920), and the average high school GPA was 2.78. Based upon quantitative admissions criteria, UMES is regarded as among the least selective institutions of higher education (IHE) within the University of Maryland system. Undergraduate first-time, full-time second year retention has varied between 64% and 71% over the past ten years.

Physics courses are taught within UMES's Department of Natural Sciences (DNS). In the fall 2015, DNS was home to 522 undergraduate majors in Chemistry, Biology, Biochemistry and Environmental Sciences and 48 graduate students. At that time, 61% of DNS undergraduate students were African American as were 37% of the graduate students. Typically, 48% of all undergraduates receive Pell Grants.

Theoretical Framework

The President's Council of Advisors on Science and Technology (2012) claims high performing students frequently switch majors because of uninspiring introductory courses. Many students, particularly underrepresented minority students, cite an unwelcoming atmosphere created by STEM faculty as a reason for their attrition (2).

Recently, Wanzer et al. (3) advanced the instructional humor processing theory (IHPT), an integrative theory that draws from the elaboration likelihood model of persuasion (4). For humor to facilitate learning, the IHPT asserts that students need to do two things; first perceive and second resolve the incongruity in a humorous instructional message. The IHPT proposes that the recognition of humor will increase students' attention. Wanzer et al. (3) concluded that the humor related to course content may increase learner motivation and his/her ability to process messages. Further, the researchers found relevant humor does not distract from the instructional message. Humor reinforces learning by making the information more memorable and positively affects levels of attention and interest. Appropriate humor positively influences learners' affective responses (5). However, using humor to support learning has its challenges. Finding high quality cartoonists with sufficient artistic skills and in-depth knowledge of STEM disciplinary content difficult. Consequently, this obstacle has likely restricted the use of cartoon associated humor in science classrooms. As an additional challenge, one of the first author's experiences at UMES suggests that many students struggle to visualize word problems; this, in turn, confounds students who lose interest in the material and/or become lost within the content. Preliminary data from an unpublished pilot study indicated that in a class of 30 students, only two students attempted to answer a question. We believe the low response rate stems from the students' failure to visualize the problem. Yet the same question combined with a supporting cartoon created a clear picture of the scenario. The cartoon humorously depicting a physics problem created interest and fomented discussion.

Our preliminary results suggest that the students see themselves within the context of the practice questions and that stimulates enthusiasm and class engagement. We believe the cartoon supports students' visualization of the question and the students are better prepared to engage a conceptual difficulty concept and are more likely to develop a correct response.

Cartoon Use in STEM Undergraduate Education

Several lines of research show the potential of cartoons in science education. Naylor and Keogh (6) developed, evaluated, and refined the use of concept cartoons as an engagement tool for STEM students. They have also found that the concept cartoon approach minimizes classroom management problems by promoting focused discussion and student motivation (7). Chin et. al. and Ekici et. al. report that teaching via concept cartoons enhances conceptual understanding by clarifying misconceptions and motivating students (8, 9). Additionally, several aspects of concept cartoons make them relevant to promoting argumentation in science courses (10).

METHODS

Cartoons

The project affiliated cartoonist created 30 cartoons which illustrated concepts central to the fundamental laws of motion. These cartoons were developed over an exploratory phase, where the Principal Investigator (PI) and the cartoonist worked together in an iterative process to assure the successful and conceptually accurate development of cartoon content. They then used the first year to collect data on initial perceptions and feedback on cartoon use from students enrolled in introductory physics courses.

The PI introduced cartoons in three physics courses during the 2017-2018 academic year: General Physics I – Mechanics and Particle Dynamics, Introductory Physics II, and General Physics III – Electrodynamics, Light Relativity and Modern Physics. Sixty-three undergraduate students were enrolled in these three courses and were taught with the use of the cartoons. By introducing the cartoons in three courses, the PI was able to explore the use of cartoons with a cross-section of students which in turn allowed for a refining of the cartoons and their subsequent use in different courses.

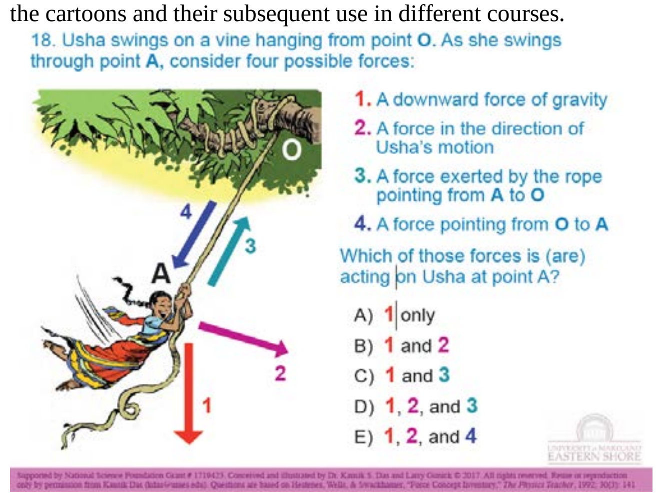


Table 1. Cartoon Assessment Student Survey: Assessment Domains and Corresponding Survey Items

Student Learning Domain	Student Affect Domain	Coherent Presentation Domain	Appropriate Design Domain
The cartoons help in showing the concepts we are learning in class.	The cartoons engage my interest in learning physics.	The cartoons are easy to understand.	The humor in the cartoons is appropriate.
The cartoons help me better understand concepts in the course.	I enjoy answering the cartoon questions.	The language used in the cartoon is easy to understand.	Cartoon pictures are easy to understand.
The cartoons help me remember the material taught in class.	I like using the cartoons to help me learn physics.	The questions are clearly stated.	The cartoons are culturally appropriate.

Table 2. Cartoon Survey Items: Ranking by Mean Score

Survey Item	μ	SD
The humor in the cartoon is appropriate.	3.00	0.00
The cartoons are culturally responsive.	3.00	0.00
The cartoons engage my interest in learning physics.	2.96	0.19
I like using the cartoons to help me learn physics.	2.96	0.19
The cartoons help in showing the concepts we are learning in class.	2.93	0.26
Cartoon pictures are easy to understand.	2.93	0.38
The language of the cartoons is easy to understand.	2.89	0.31
The cartoons help me remember the material taught in class.	2.89	0.42
The cartoons are easy to understand.	2.86	0.45
The questions are clearly stated.	2.82	0.48
I enjoy answering the cartoon questions.	2.81	0.48
The cartoons help me better understand the concepts in the course.	2.79	0.51

The project developed a cartoon assessment survey to collect students' perception on the use of cartoons in their physics courses. The survey examined four domains: student learning, student affect, coherent presentation, and appropriateness of design. Student respondents used a three-point Likert scale (1 – disagree, 2 – neither agree nor disagree, 3 – agree) on survey items in each of the four assessment domains. See table 1 for all survey items.

Undergraduate Research

During the 2017-2018 academic year, the project provided 30 students with undergraduate research experiences, of which, 13 participated for the entire academic year. Seven additional students participated as part of their independent studies in the Physics III lab.

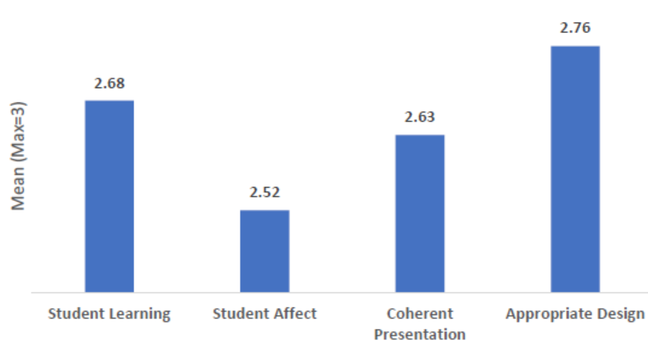
The project administered an online version of the NSF-funded Undergraduate Research Student Self-Assessment (URSSA) survey instrument to collect data on students' experience with the undergraduate research experiences. Eleven of the 13 STEM students who participated in undergraduate research for the full academic year responded to the online survey (69.2% response rate). Most of the respondents were engineering majors, followed by two chemistry majors and one biology major. Only two respondents were female students.

Four core constructs of the URSSA establish acceptable subscale reliability (14). These constructs describe the extent to which students experienced increased cognitive skills and affective learning. The constructs and associated reliability include: thinking and working like a scientist – $0.88 \leq \alpha \leq 0.90$; personal gains – $0.90 \leq \alpha \leq 0.91$; (research) skills – $0.91 \leq \alpha \leq 0.92$; and (research) attitudes and behaviors – $0.83 \leq \alpha \leq 0.84$.

RESULTS

During the spring 2018 term of exploratory implementation, students enrolled in (PHYS161) took the cartoon assessment survey towards the end of the semester. Twenty-one of the 61 (34%) total students introduced to the physics cartoons in the spring 2018 semester completed the survey. The cartoons received an overall mean rating of 2.65 (SD = .13), which indicates positive student feedback on the use of the cartoons in physics instruction. Among the survey constructs, students rated the appropriateness of the design of the cartoons the highest with a 2.76 mean (SD = .12), followed by student learning, coherent presentation, and student affect with respective 2.68 (SD = .15), 2.63 (SD = .12), and 2.53 (SD = .05) means (See Figure 1). The high ratings on the appropriate design domain are particularly important since this subscale measures students' perception of the cultural appropriateness of the cartoons. Given the HBCU context and the focus of the project on broadening STEM participation of underrepresented minority students, explicit attention in the cartoon design was given to reflect diverse representation in characters and subject matter to avoid demeaning and disparaging stereotypes. In fact, the survey item asking if "the cartoons are culturally appropriate" had the highest mean score, *M* = 2.9:

Figure 1. Student Cartoon Assessment - Exploratory Phase

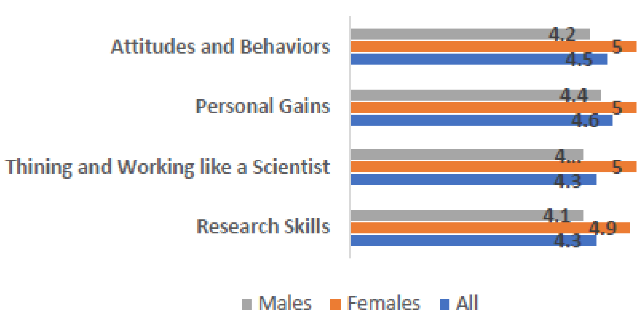


Students also rated the cartoons highly for their contribution to student learning. The second highest-rated survey item, *M* = 2.81, indicates the extent to which the cartoons elucidate physics concepts: "The cartoons help in showing the concepts we are learning in class." After physics content, the next highest rated survey item, M = 2.76, focused on the difficulty level of the language used in the cartoons: "The language used in the cartoons is easy to understand." The fifth highest mean score, M = 2.71, corresponded to two survey items. One on student learning focused on content retention: "The cartoons help me remember the material taught in class," and the other focused on the humor associated with the cartoons: "The humor in the cartoons is appropriate."

Undergraduate Research Experience

Students responses on the URSSA instrument assessed the extent to which they made individual gains in undergraduate research based on their response to each survey item on a five-point Likert scale where 1 = no gain and 5 = great gain. As shown in Figure 2, students reported experiencing considerable gains in each of four core areas. Students experienced the greatest growth in personal gains (e.g., developing patience with the slow pace of research), followed by gains in their attitudes and behaviors (e.g., feel a part of a scientific community), and finally, experiencing equal gain in research skills (e.g., keeping a detailed lab notebook), and in thinking and working like a scientist (e.g., understanding the theory and concepts guiding my research projects.) Interestingly, female students experienced greater gains in all four core areas than their male counterparts. However, this finding is viewed with caution given the small sample size.

Figure 2. Student Growth: Undergraduate Research



Students were asked about the motivations behind their desire to participate in undergraduate research. The leading reasons included: to explore their interest in science, to gain hands-on experience in research, to clarify whether to pursue scientific research as a career, for the intellectual challenge, and to work more closely with the PI. In fact, students rated the research mentoring from the PI very highly (4.4), as well as the nature of the research (4.4), and the culture of working with other students on the research team (4.5). Students attributed the high quality of the research experience to the project PI as represented in the following comments from two different students. A pseudonym is used in reference to the individual mentioned within the quote below.

My professor Dr. Smith personally asked me to do research. He is single-handedly the greatest professor I have very had and I knew I couldn't give up this opportunity. (Male Engineering Major)
Excellence advice from my mentor and the great sense of doing work as a researcher. (Male Engineering Major)

Students reported that the undergraduate research experience also positively impacted the likelihood of whether they will pursue STEM pathways. Among the STEM pathway options, 50% of the respondents reported that they are extremely more likely to enroll in a Master's program in STEM. The majority are much more likely to enroll in a joint MD/PhD program (62.5%), a Masters program in STEM (62.5%), and a PhD program in STEM (50%). As a caveat, these students likely possessed an interest in scientific research prior to the undergraduate research experience, but the project heightened their interest in pursuing graduate STEM programs. The following student comments capture the direct influence of the research experience on prospective STEM pathways.

My research has been the foundation of my entire undergraduate experience. It has greatly help[ed] me put my life into perspective and help[ed] me determine what I want to do in my future career. (Male Engineering Major)

It made me really consider grad school and I was intrigued by my new found knowledge. (Female Engineering Major)

My research experience opened my eyes as graduate school actually is and how it feels to doing research. I decided to go to graduate school after being involve[ed] in research projects. (Male Engineering Major)

Students had few comments on improving the undergraduate research experiences. The suggestions included having the opportunity to receive a stipend instead of or in addition to one academic credit, more time to do the research in the lab, and the opportunity to attend more conferences. One student said, "It's pretty great the way it is."
The prolific dissemination of manuscripts, posters and conference presentations indicates the robust nature of the research component with undergraduates. The level of scholarly activity in collaboration with students is an important strength of the project in its first year of implementation.

DISCUSSION AND CONCLUSION

Cartoons

This study examined cartoon development and implementation in the project's first year. The study found that the 30 physics cartoons are culturally-responsive, represent high quality in design and presentation, and amenable to improve student learning and student affect. Additionally, the high rating for the question asking about cultural appropriateness indicates that the cultural relevance and sensitivity of the cartoons are in alignment with the HBCU context of educating underrepresented minority students.

Undergraduate Research

The project successfully provided undergraduate research experiences to underrepresented minority students. While the project provided undergraduate research experiences to 30 students, the study focused on the experiences and results of the 13 students who worked directly with the PI outside of physics classes. The results from the survey on undergraduate research as reported by students (69.2% response rate) reveal positive student outcomes in cognitive and affective learning. Considerable personal growth was seen in students (e.g., developing patience with the slow pace of research), attitudes and behaviors (e.g., feel a part of a scientific community), research skills (e.g., keeping a detailed lab notebook), and thinking and working like a scientist (e.g., understanding the theory and concepts guiding my research projects). Female students experienced greater gains than their male counterparts. However, this finding is viewed with caution given the small sample size.

In addition to the student growth in cognitive and affective learning seen in the first year of implementation, the undergraduate research experience also positively influenced student interest in graduate study in STEM. Several students credited the PI for the self-realization to pursue STEM pathways at the graduate level. The involvement of undergraduate students in the robust level of scholarly activity and dissemination will serve them well in graduate school readiness and preparedness. Gender differences will continue to be examined as the project moves forward in its second year.

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