

The Eurasia Proceedings of Educational & Social Sciences (EPESS), 2018

Volume 9, Pages 1-10

ICEMST 2018: International Conference on Education in Mathematics, Science and Technology

Integrated Development and Assessment of Mathematical Modeling Practices for Culturally Responsive STEM Education: Lionfish Case Study

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Abstract: Real-world problems often demand interdisciplinary solutions, and thus provide opportunities for cross-disciplinary instruction and learning within the mathematical sciences and STEM fields. Building on the vision of The Mathematical Sciences in 2025 (National Research Council, 2013) and with the motivation to prepare the students of the 21st century, interdisciplinary teacher teams are created to work together with students, university faculty, and community experts, towards building instruction around solving problems on locally relevant STEM challenges. The goal of this research program is to provide equitable access to quality STEM instruction for all students while using culturally responsive practices. Since 2014, with support from the National Science Foundation, in-service STEM teachers, students, and university faculty have been participating in year-long professional learning community (PLC) activities on STEM projects around culturally relevant topics such as lionfish population dynamics and control, water quality, and green home design. Based on the emerging local best practices with PLCs around interdisciplinary projects, these PLCs support the development of interdisciplinary knowledge and practices by students, teachers and the community for learning mathematical sciences and STEM, both in and out of school settings. Using the case of the lionfish project as an exemplar for culturally responsive STEM projects, we discuss how focused professional development sessions for teachers on the mathematical and scientific modeling of lionfish population dynamics and control using discrete, continuous and statistical methods furthered this development.

Keywords: Mathematical modeling, Assessment, Culturally responsive STEM education, Project based learning, Professional learning communities, Interdisciplinary mathematical and scientific practices

Introduction and Motivation

Despite the need, students in the Caribbean struggle to identify themselves with STEM related professions. As part of providing equitable access to high quality STEM education, educators are being asked to find ways to consider students' cultural and linguistic backgrounds and to develop a closer fit between their home culture and the culture of the school (Brown, 2007). This practice has been referred to as *culturally responsive teaching*. Research suggests that the academic achievement of ethnically diverse students can improve when they are taught through their own cultural and experiential filters (Au & Kawakami, 1994; Gay, 2000; Hollins, 1996; Kleinfeld, 1975; Ladson-Billings, 1995). Within inquiry-based teaching methods, it has further been suggested

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- Selection and peer-review under responsibility of the Organizing Committee of the Conference

that the motivation for inquiry should be grounded in personal interests, local social and environmental concerns, and community values (Freire, 2000).

In STEM fields, numerous calls have highlighted a need for a heightened emphasis on mathematical and scientific modeling, on more interdisciplinary practices, and on more integrated STEM projects for K-16 students (CCSS, NGSS, NRC, NCTM). Integrated STEM projects, in particular, are known to increase student STEM interest via authentic problem solving, collaboration, and the building of realistic models and solutions (Fortus et. al, 2005). Further, integrated STEM can develop better learning outcomes as students build their knowledge using the world around them (Satchwell & Loep, 2002). Project-based learning (PBL) is known to be an effective method of STEM integration, with PBL building on a series of inquiry based, open-ended activities related to a thematic topic that can be approached from multiple disciplinary perspectives (Satchwell & Loep, 2002). For example, population dynamics and control is a theme with deep running, cross-cutting ideas that can be used to build bridges across the STEM fields. Further, within the mathematical sciences, population dynamics allows students to experience mathematics from the perspective of another discipline, to be exposed to key ideas from complementary points of view (continuous and discrete, deterministic and stochastic,; exact and approximate), and to incorporate concepts and methods from data analysis, computing, and mathematical modeling, thereby meeting the recommendations of the MAA (2015). By emphasizing discrete population modeling techniques, educators can respond to the recent advances in the computational sciences, which have effectively increased the importance of teaching discrete mathematics. It has also been suggested that simultaneously teaching difference equations/recursive methods alongside continuous approaches to population modeling can allow students to encounter the rich interplay between continuous and discrete approaches (Ekici & Plyley, 2018), and may enhance aspects of students mathematical learning (Plyley & Ekici, 2018).

In this paper, we discuss how the first two authors engaged in-service STEM teachers in locally relevant STEM projects while providing year-long support through a directed professional development program. The goal of the program is to make STEM learning experiences more locally-accessible, culturally-relevant, and interesting for students living in underrepresented or isolated communities. Through this process, the authors work to form *professional learning communities* (PLCs) consisting of STEM teachers, university faculty, students, and community partners, which focus on locally relevant and culturally responsive projects. Our research questions are as follows:

1. How do culturally responsive practices provide equitable access to STEM learning for secondary students and STEM community, in and out of the classrooms, through a population dynamics project?
2. How can we provide teacher professional development to interdisciplinary STEM teacher teams in response to their needs in implementing a population dynamics and control project?

Methodology - Collaborative Action Research in STEM PLCs

Structuring STEM Professional Development

Since 2013, with funding from the National Science Foundation (NSF), the University of the Virgin Islands (UVI) has provided year-long training and support for in-service STEM teachers through the *Virgin Islands Institute for STEM Education Research and Practice* (VI-ISERP), an organization chartered in 2014. The first author served as the founding research director of VI-ISERP from 2014-2017, with second author assuming this role thereafter for St. Croix and beyond.

As part of its mission, VI-ISERP has created the following structure for in-service STEM teacher professional development. Interdisciplinary teacher teams are formed and partnered with community experts and university faculty to investigate culturally relevant STEM challenges. The participants take part in year-long PLC activities centered around integrated STEM projects; for instance, lionfish population dynamics, water quality, green home design, and robotics. The PLCs are structured to provide sustained support on the development and implementation of the project, both in and out of school, with critical feedback from other PLCs during joint meetings. Within the context of each project-centered PLCs, there is a reciprocal learning exchange between 'mentor teachers' that lead the project and the other members of the wider educational community. The goal of this research program is to provide equitable access to quality STEM instruction for all students using culturally responsive practices and to develop local best practices.

With collaborative action research known to develop the capacity of teachers as scholars of practice (Sagor, 2010), the PLC participants are enrolled in graduate level action research courses at UVI. As part of their process, teachers form research questions, collect and analyze data, and present their findings as the interdisciplinary projects develop their stories. Participants are taught a mixed method approach with supportive quantitative and qualitative data.

Further, VI-ISERP provides a concentrated 10 day professional development session each summer. Following this event, teachers take part in year-long follow-up activities focused on developing advanced disciplinary perspectives, standards-based interdisciplinary connections, mathematical modeling techniques, and pedagogical and technological training relevant to their interdisciplinary projects. To this end, the authors developed *STEM Teacher Circles* (Ekici & Plyley, 2017). The STEM Teacher Circles run two to three times each semester, building on the summer workshop and action research training.

An Exemplar STEM Professional Learning Community - The Lionfish Project

As an exemplar, we will describe both the development (including student-led research questions and conjectures) and the action research steps of the PLC that was formed around the population dynamics and control of the invasive lionfish population near St. Croix. Although the number of persons involved in the project changed over time, two mathematics and two science teachers began leading the project with partial support from approximately 30 other STEM teachers in the wider educational community. The project took place at various times in-class, after school, and on weekends with the participants being especially involved in community outreach activities during these after-school hours.

This lionfish research project has gone through three cycles of iteration of action research since 2015. The initial teacher team (A. Acosta (mathematics), N. Santana (science), and R. Gordon (science)) used their first cycle of action research to launch their project and refined their short-term and long-term project goals, and their interdisciplinary learning outcomes, as they collected and analyzed their data. This process acts to simultaneously improve their practice and activities with students, their outreach activities with community members, and the student and teacher outcomes of the project. During the second cycle of action research, the participating teachers (NSantana, R. Gordon, I. Rosado Jr. (mathematics), A. Isaac (M.Ed. student)) were joined by ten total students who had taken part in the project during the first year; these students volunteered to participate in the summer workshops and they assisted with the development of PBL activities that were implemented by the teachers during the school year. With travel support supplied by VI-ISERP, the teachers have been presenting the results from their action research locally and internationally (i.e. Gordon, Santana, Acosta, & Ekici, 2016).

The student-led orientation of the project became an “*Eat to Beat*” campaign, where students investigated whether they could counter the invasive lionfish population by promoting the lionfish as a food source; an approach which allowed the STEM teachers act as community activists (see Harvey and Mazzotti, 2015). Lionfish are now being harvested recreationally and commercially throughout most of the invaded regions, and are served in over 160 restaurants (NOAA, 2016). The teachers formulated the following learning objectives for the *Eat to Beat* project:

- Introduce lionfish as a food source, have the public consumers view lionfish as a delicacy, and teach the community how to safely handle, clean, prepare, and cook the lionfish.
 - Develop, implement, and analyze a rubric to assess the public perspective on lionfish as a food source.
 - Educate the public on the dangers and impacts of invasive lionfish to the ecosystem and economy,
 - Inform the community about the negative impacts of lionfish on the local food supply.
 - Stay up-to-date with science and technology behind effective lionfish capture and counting.
 - Organize and support lionfish derbies and create a greater public demand for lionfish.
- Justifications for the *Eat to Beat* project came from teacher directed student research into the phenomena. Samples of student reasoning include:
- In the Bahamas, lionfish are estimated to eat 1000 pounds of native reef fish per acre per year. So if we don't remove the lionfish, our reef fish may disappear and the health of our reefs will diminish.
 - Since the lionfish has no natural predators in the Caribbean, humans should be inserted into the ecosystem to act as the main predator.

To develop the identity and agency of participants, the *Eat to Beat* team designed a logo for their campaign (see Figure 1). They choose the name *Caricudas*, combining the names of their team mascots from two neighboring high schools, St. Croix Educ. Complex (*Barracudas*) and St. Croix Central High(*Caribs*).



Figure 1. Student lionfish campaign logo

They also designed lionfish costumes and masks for some of the community events they participated in. To assess the effectiveness of their campaign, the team designed surveys to assess community awareness of the lionfish problem and their attitudes towards the consumption of lionfish. These surveys were administered during the St. Croix Annual Agricultural Fair, which is an important cultural festival in the Caribbean. In addition, one year the students prepared lionfish food samples and also took part in NSF funded *Science Cafes*, where they presented to the public alongside the project members and Dr. Tyler Smith (National Science Advisory Board Member), discussing the edibility of lionfish, in an effort to combat the ciguatera neurotoxin controversy.

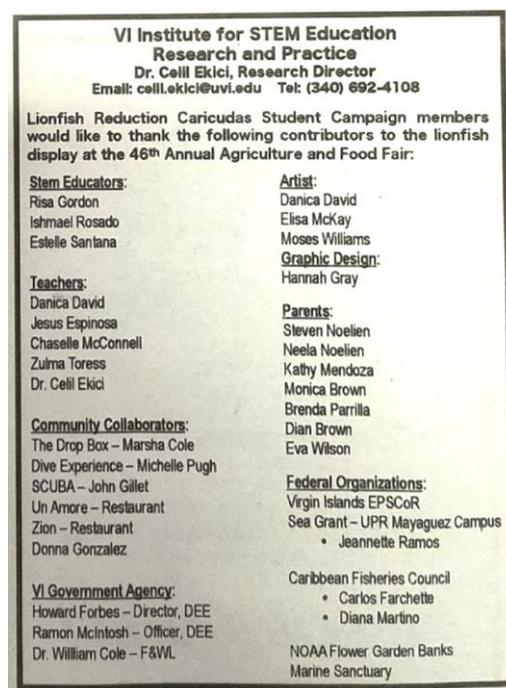


Figure 3. Lionfish campaign advertised in newspaper, April 16, 2017

During the dish sampling, the safety of lionfish consumption was repeatedly questioned. In fact, even some student participants ultimately conjectured that *“even if you take the spikes out, the level of ciguatera will be too high to be safe....since it is high in food chain.”* Student research had students find that (in 2014) ciguatera toxin levels in lionfish collected from waters surrounding the USVI was found in 40% of lionfish, with about 12% having levels that exceed safe consumption levels provided by the U.S. Food and Drug Administration (FDA) (see Robertson et. al, 2014). However, deeper analysis revealed that in fact only one lionfish from St. Croix was actually included in the 2014 sample, and identifying the location of the catch suggested that the degree of accumulation of ciguatoxin may be habitat specific. Participants also discovered that none of the samples from other locations (i.e Trinidad and Tobago) demonstrated levels above FDA regulations. This caused students to revise their earlier conjecture. Considering the controversies and health implications, the project team sought further expert support, and project leaders had two experts provide seminars for participants and the public at community events revealing myths behind potential ciguatera poisoning with lionfish. Indeed, later research suggested that there is no evidence that lionfish in ciguatera-free areas are a threat to public health (Wilcox & Hixon, 2015; Hardison et al., 2018).

Another issue that students had to address during the campaign was: *is it safe to eat as much lionfish as you want?* Students were concerned the amount of mercury that would be consumed from lionfish. The teachers facilitated activities which compared mercury levels in edible fish (lionfish average .07 mg/kg of mercury, compared .91 mg/kg for black grouper, .25 mg/kg for yellowfin tuna, and 1.51 mg/kg for king mackerel). They ultimately determined that mercury was not a concern for lionfish consumption.

Ultimately, the data analysis by the participants determined that many in the population (particularly, the older demographic) were unwilling to incorporate lionfish into their diet. Iterating, the project members re-assessed their strategy and revised their plan for lionfish harvesting. In particular, they included the use of lionfish as agricultural mulch into their model for lionfish control (along with human consumption). Following a visit to a local farming supply store, they re-assessed after learning about the local farming practices involving mulch on the island. More extreme hypothetical avenues, including using the neurotoxin of a lionfish as a bioweapon, were suggested, but ultimately dismissed due to the obvious safety issues in this hands-on learning environment. However, these questions and discussions led to student inquiries into health science related issues, and the teachers followed up with further investigations into neurotoxicity and treatment options for the lionfish venom, which is found in the needle-sharp dorsal, pelvic and anal fins of a lionfish. Biology in-class sessions henceforth have included modules on differentiating venom and poison.

Follow-up Focus Group with Project Leaders - Limitations

Following the project implementation, focus groups and interviews were conducted with the project leaders. It was noted that although the project leaders examined the trends in the local population's attitudes toward lionfish, they acknowledged that they *“didn't have quite enough time to analyze the data with their students in the classroom”*. Further, some teachers commented that the alignment of the project activities did not fit well with the geometry topics that mathematics teacher was teaching at the time. They reflected on the importance of administrative support so that they could receive course assignments that better allowed them to integrate the aspects of their project; in particular, survey data analysis. They noted that the absence of the statistics teacher that was initially involved in the project impacted the integration of statistics topics.

Responding to Research Questions

The *“Eat to Beat”* PLC was particularly exemplar in its engagement of the community, industry experts, partners, resources. These efforts were mostly coordinated by project leader N. Santana during the 2016-2017 school year (see Figure 3). For example, the project team utilized community partners such as the *Reef Responsible* initiative; a sustainable seafood initiative designed to help create a sustainable seafood industry in the U.S. Virgin Islands. With *Reef Responsible*, the campaign implemented a lionfish festival that had chefs compete for the best lionfish dish. The ample community partnerships helped to ensure the project built locally responsive and community engaging practices. Further, the level of engagement and diversity of participants and activities, both in and out of the classrooms, provided ample evidence of equitable access to interdisciplinary STEM learning with students and the community.

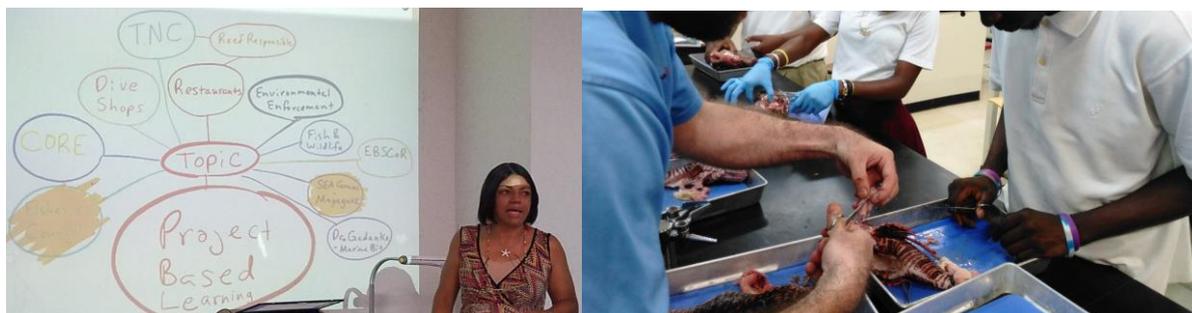


Figure 3. Ms. Santana portraying community partners and a community expert assisting

PAGE 4 The Bus FRIDAY, FEBRUARY 17, 2017

Students study impact of lionfish on ecotourism industry

BRITNEY KNIGHT



ST. CROIX — Students from the St. Croix Central High School and St. Croix Educational Complex have partnered to study the impact lionfish are having on fishing and ecotourism industry in the Virgin Islands.

The students are working through the University of the Virgin Islands science, technology, engineering and math program, according to university statement.

The students hope to promote the consumption of lionfish and plan to do so by introducing it to the palates of residents and visitors alike. Once the public has been provided with information and learn that the lionfish is high in healthy Omega-3 fatty acid, has zero saturated and trans fat and are a great source of protein and is not poisonous, they will be willing to buy and consume the species, the release stated.

Studies by scientists have concluded that lionfish pose no greater threat of ciguatera than the popular species of fish consumed by locals and visitors to our island.

According to the statement, understanding the magnitude of the impact that an uncontrolled population growth of lionfish will have on commercially viable juvenile fish in the coral reefs, the students have begun a campaign to educate and raise awareness in the community that the lionfish is edible once the spines have been properly removed. They intend to introduce the lionfish as a delicacy so it can become a popular food choice on the table of the Virgin Islanders, the release stated.

Demand for lionfish by consumers will reduce the numbers of lionfish in the marine environment and a balanced population of lionfish will help protect commercially viable juvenile fish, the release stated.

To launch the campaign the students will participate in this weekend's Agriculture and Food Fair where they will provide information on lionfish, according to Nora Santana, one of three STEM educators assisting students.

The public is invited to visit the lionfish display from 11 a.m. to 3 p.m. on Saturday, from noon to 3 p.m. on Sunday and from noon to 4 p.m. on Monday. There will be information as well as varied dishes of lionfish to sample, Santana said.

Submitted photo

Students from St. Croix Central High School and St. Croix Educational Complex have partnered with UVI to study the impact lionfish are having on fishing and ecotourism industry in the Virgin Islands. The public is invited to visit the lionfish display from 11 a.m. to 3 p.m. on Saturday, from noon to 3 p.m. on Sunday and from noon to 4 p.m. on Monday. There will be information as well as varied dishes of lionfish to sample.

Figure 4. Eat to Beat students in the local newspaper

Responding to the second research question, professional development was provided based on teachers' emerging needs in implementing culturally responsive integrated STEM PBL units. For the lionfish project, STEM Teacher Circles were designed specifically in response to teachers needs in implementing the project with their students; specifically, the first two authors provided training in the mathematical and scientific modeling of population dynamics for a group of about 35 STEM teachers in the summer of 2016 and twice in the fall of 2016. This training was purposefully designed to make mathematical content of modeling more accessible for secondary STEM learners, and especially when incorporating advanced ideas like irregular harvesting. We also provided statistical modeling approaches for parameter estimations to study growth rates. In addition to mathematical modeling perspectives, we invited lionfish experts to share their research perspectives on lionfish, such as the toxicity level. To support meaningful integration of technology, we offered training and connections to relevant technologies, such as spreadsheet modelling in *Microsoft Excel* and dynamical system modeling with *Insightmaker*, which is a free open-source general-purpose tool and platform for web-based modeling & simulation and sharing (Fortmann-Roe, 2014). It is available from InsightMaker.com.

Assessment of Culturally Responsive STEM PBL Student Learning

Integrated STEM lessons present concepts that are not always unidimensional for their measurement and assessment. Student ability in a core subject at a grade level is usually conceptualized as a unidimensional trait for assessment purposes. Math ability, for example, is conceptualized as a unidimensional trait which allows us to assign numbers to students on a continuum to represent the students' ability. For integrated STEM learning, assigning numbers to student ability on one dimension is not an option unless STEM ability is conceptualized as a two-level model. STEM ability could be modeled with a higher order complex ability, with lower level abilities representing those that are unidimensional, such as math ability, problem solving, or making connections. Multidimensionality of integrated STEM learning aligns with the assumption that students are provided lessons that will require them to use their knowledge in science, technology, math, and engineering while being able to make connections amongst them. Integrated STEM learning materials do not necessarily always tap into all core areas of STEM. Sometimes only a subset of the four core areas is integrated in a STEM learning unit. In addition to the core area abilities, other traits such as problem solving, communication and collaboration, making connections, and interpreting results become major learning outcomes from PBL units.

Within the purpose of highlighting the possible learning outcomes that could be fostered with integrated STEM learning PBL units and the purpose of exemplifying the ways to measure those outcomes, we provided teacher training on the assessment of mathematical modeling and integrated project based STEM learning outcomes

incorporating culturally responsive practices. Performance assessment is investigated as it provides a better platform to measure project based learning outcomes in various dimensions including problem solving, communication and collaboration, making connections, and interpreting results. Formative assessment is partnered with performance assessment for the training. Within the formative assessment, learning and assessment goes hand in hand, where teacher guides, observes, measures, and provides feedback during the learning process.

We adopted a performance assessment rubric as developed by the New York Performance Standards Consortium (2016). Teachers are asked first to work in pairs on culturally relevant STEM tasks, such as lionfish and queen conch population modeling (see Figure 5).

It's Conchservation Time!

VI STEM Institute Summer Workshop

Let's focus on one particular fishing spot that is known for conch, the Lang Bank, east of STX, and let's assume that it covers 1 hectare of ocean. Suppose that a dive team is sent there to determine how many conch live there.

1. On the first dive, they catch and tag 12 conch. On the second dive, they catch 15 conch, and 3 of those 15 have already been tagged.

(a) Prior to yesterday, did you know how to estimate population based on mark/recapture data?

A. YES

B. NO



1. Estimate the approximate population of conch in Lang Bank.

$$\frac{12 \cdot 15}{3} = 60$$

Figure 3. Conch activity sample

Each pair received another pair's solution to evaluate, while applying the rubric. After using the rubric, teachers are asked to discuss the rubrics and how they work for integrated STEM learning assessment. Some participants supported the rubric, believing it to be a good tool to establish a standard way to measure student performance, whereas others criticized it. Several teachers indicated that a rubric aligning with the performance attributes simplifies the measurement process. Some of the criticism focused around the clarity of the language and descriptions of one or more performance indicators and the difficulty of classifying the observed performance with the given performance categories. One teacher indicated that it was hard to evaluate the task with no answer key available, which is common in project-based learning. One science teacher indicated that the assessment process was hard for science teachers due to the inherent math content. When integrated STEM learning material is presented, students might be required to use their knowledge in any, all, or several, areas of STEM and the assessment becomes harder for teachers who are not comfortable in one or more of these areas.

Reliability is one of the most essential features of a good measurement. For a performance assessment with the use of a rubric, inter-rater reliability is expected to be established. Research from the teacher training on the assessment of mathematical modeling and integrated STEM learning outcomes with PBL units incorporating culturally responsive practices (Alagoz & Ekici, 2018) found that the teachers were pretty consistent in using the rubric for problem solving, and reasoning and proof, yet their grading was not as accurate for the communication trait. It is recommended to further calibrate the grading process. Alagoz and Ekici (2018) presented a multidimensional measurement of mathematical modelling which offers individualized feedback for instructional support to mathematics teachers with evidence based on student performance. This multidimensional measurement approach identified distinct attribute mastery profiles among learners and provided fine grained individualized feedback.

Validity is another essential feature of a good measurement. Even though validation is an iterative process, there are steps to be taken at the beginning of the assessment to make sure the assessment process is appropriate for measuring the outcomes we would like to measure. Large scale assessments go through standard setting procedures to establish cutoff scores on continuous proficiency scales which are used later to assign students into categories. When we use previously created rubrics that presents performance indicators to place students into categories, the standard setting process is inherently present in the rubric. The rubric becomes the standard. It is essential to make sure the rubric has the potential to set the standard which consequently contributes to the validity of the assessment. In a validity study of mathematical modelling, Ekici and Alagoz (2018) provided an approach to facilitate a standard setting like process to a formative performance assessment for mathematical modeling, coordinating disciplinary and interdisciplinary connections. Expert teacher practices guided to establish meaningful and valid measurements for untraditional competencies with interdependencies as in the case of integrated STEM learning tasks.

Building Evidence on Locally Effective Culturally Responsive STEM Practices

Building on Ladson-Billings's seminal work (Ladson-Billings, 1995), we studied eight indicators of culturally responsive practices by STEM teachers (Greenstein & Ekici, 2017). We added more community engaging practices with exemplars:

- Communication of High Expectations
- Active Learning Methods
- Teacher as Facilitator
- Inclusion of Culturally and Linguistically Diverse Students
- Cultural Sensitivity
- Reshaping the Curriculum (not top down)
- Student Controlled
- Classroom Discourse
- Small Group Instruction and Academically Related Discourse

One of the emerging need for teachers has been on the assessment of mathematical modeling practices and learning outcomes with the integrated STEM learning projects. Supplemental trainings were developed and provided by Alagoz and Ekici between Spring 2016, and Summer 2017 in the educational measurement and validity of modeling assessments (Alagoz & Ekici, 2018). Building on the culturally responsive indicators of practice (Greenstein and Ekici, 2017), we aimed to assess the degree to which:

- The units are relevant to students community and culture
- Students see themselves represented in curricular materials
- Materials are accessible
- Materials promote active, inquiry-based learning
- STEM and other disciplines are integrated
- STEM curriculum is connected to local concerns and social justice issues

Partial results in relation to mathematics teachers' practices can be found in (Greenstein & Ekici, 2017). The impact of culturally responsive pedagogies for STEM teachers are currently being investigated upon revision of the instruments.

Recommendations

Building professional learning communities around locally relevant and culturally responsive relevant STEM problems can be time consuming. Having specialized roles, for example, having one of the team members focus on community engagement and outreach experience, was beneficial in this case. This STEM learning project was a highly rewarding inclusive experience for students, teachers, and the community participants. The lionfish project was ambitious, as it was driven and initiated by the teachers and their students. A powerful aspect of the project was that students and teachers assumed the role of community activists. The level of student engagement necessitated time that was beyond regular class time, but the level of student interest and engagement meant that students were willing to do this, even during the weekends. Students-agency and identity as scientists and STEM education researchers were fostered while they worked in their communities interacting with multiple stakeholders and scientists. While the ultimate objective of controlling the lionfish population by

human consumption was ultimately beyond the scope of this project, the process allowed students and each member of learning-community to observe the potential impact and take part in an extremely authentic and relevant STEM challenge. Later on, as the project progressed, the team observed that similar campaigns were conducted especially in Florida (Harvey and Mazzotti, 2016). As an ongoing project, team members have decided to revisit to delineate the scope and sequence of activities, to provide more sustainable practice for other teachers and students to emulate.

Acknowledgements

This work is partly supported by the National Science Foundation (NSF) under Grant Number 1355437. Any opinions, findings, and conclusions or recommendations expressed here are those of the authors and do not necessarily reflect the views of NSF. During the implementation of the lionfish project, Ms. Nora Santana as a science teacher has been greatly instrumental leading the “Eat to Beat”-Lionfish project orchestrating activities in and out of classroom with community partners. Mr. Rosado Jr. as a mathematics teacher from Virgin Islands Department of Education provided support as mathematics teacher and incorporating relevant technologies related to surveys and their analysis.

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