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Incorporating citizen science engagement in a vector surveillance undergraduate internship

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Abstract
Citizen science is recognized as an important tool to engage the public in important scientific and environmental issues that impact them. Mosquito surveillance-based citizen science in college curricula have not received much attention even though its usage has the potential to actively engage students in inquiry and elevate student support for science. FLAGG (Florida *Aedes* Genome Group) was a course-based internship where college students engaged in mosquito egg collections, learned about disease transmission, and gained an understanding of data collection in scientific research. This paper reports on a study comparing the outcomes of FLAGG participants with students in other college internships and students who had never done an internship. Findings show that participation in the citizen science mosquito control internship not only increased knowledge and skills in mosquito abatement, but also increased confidence and to a certain extent, sense of engagement, when compared to other groups. These results support the inclusion of citizen science methods in college-based curricula, where benefits extend beyond content learning.

Keywords Citizen science · College students · Mosquito control · Science internships · Career confidence

1 Background

Citizen science bridges education with outreach, and professionals in academia with the local community [26]. With the growth of technical tool availability for the public, and customized guides, there is an increasing use of citizen science in projects ranging from population ecology to climate change, increasing the potential for data collection in various scientific fields [49]. Citizen scientist amateurs are becoming essential in project tasks that include collecting, transcribing, and processing large amounts of data alongside scientists [4]. Students can become a key component of that citizen science bridge between professionals and the community as they are community members that are being introduced to the world of academia and research. Involving students helps scientists implement educational and outreach programs to increase data collection, improve scientific literacy, and introduce more interdisciplinary approaches to research [8, 19].

Citizen science can be used to motivate students to pursue STEM in college and continue to contribute to science in a college setting [56, 60]. This incorporation of citizen science can be used to address the recent decrease in American scientific competency through interactive programs that focus on research, analysis, and interpretation in a real-word

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context [48]. Apart from improving student performance and material retention, studies such as William et al. [60] and Queiruga-Dios et al. [41] both showed an improved sense of contribution to science and a positive shift in attitude about science learning amongst student participants. As students learn to monitor their environment and communicate results, they gain skill sets that could lead them to have better employability [14, 35, 53].

Public engagement in mosquito surveillance is a relatively new field of study that has allowed for large-scale and real-time data collection of local abundance, diversity, and distribution [1, 50]. In citizen science mosquito surveillance programs, participants can be encouraged to inspect for and collect mosquito eggs, larvae, pupae, and adult stages, while accruing breeding site information [31, 32, 37, 515050ial to be used as community-built real-time outbreak warning systems [50].

The implementation of integrated tools into mosquito control has become increasingly important in Miami-Dade County (MDC), where the risk of mosquito-borne diseases like dengue and Zika has persisted and intensified due to conducive conditions for year-round transmission of vector-borne diseases [42, 47, 59]. Mosquito control reliance on insecticide application within the last century has led to a pesticide treadmill, where the continuous increase in insecticide use causes increased insecticide resistance as well as detrimental effects for ecosystems [29]. Due partially to the lack of acknowledgement of insect movement, insecticide usage has also generated controversial, unsustainable and uncoordinated insecticide applications [9, 23]. Influenced by both ecological and political issues, mosquito control has expanded to include more community engagement and close coordination in introducing biological control, educational outreach, insecticide resistance training, environmental management, and surveillance [2, 7, 21].

Mosquito control programs need to be able to maintain a cost-efficient system for surveillance, especially in times where relocation of funds or reduced available funds are apparent [30]. In the wake of the COVID-19 pandemic, multiple mosquito control programs were affected and unable to keep up with funding and personnel due to increased restrictions and health concerns leading to social distancing requirements [16]. The ability to extend community engagement through the use of volunteer organizations that involve homeowners and residents can become critical to achieving a reduction in mosquito populations [13, 18, 27, 45, 61]. Citizen science can help reduce funding costs related to active field work and increase surveillance in private areas that are difficult to access or are unreachable by truck spraying [28]. Citizen science, engagement and education can even allow for mosquito surveillance to outperform traditional mosquito control methods as it is hands-on, low-cost, and highly scalable to expand to previously unmonitored jurisdictions [34, 50].

Community engagement in mosquito control citizen science can increase residents' knowledge on how to reduce mosquito populations and therefore potentially reduce arbovirus transmission in their communities [10, 38, 39]. A great example of integrated mosquito vector management implementation comes from the largest mosquito abatement program in the United States, in the Lee County Mosquito Control District (LCMCD). LCMCD has generated courses for local funded kindergartens through high schools to teach students basic mosquito biology knowledge and control techniques based on Florida standards of mosquito control [11]. Increased knowledge would provide residents the ability to express their social concerns, increasing engagement time and intensity, and improving participant confidence, sense of community and ability to participate. Using citizen science, participants can potentially collect specimens, report their findings, and help analyze the collected data . To engage, participants need to learn about mosquito surveillance, mosquito stage and breeding spot identification, and accessible methods of control such as the use of ovitrap container reduction [12, 17]. This approach could be useful in MDC where increased urbanization near natural areas has caused mosquito vectors to thrive and increase potential resident exposure to mosquito-borne viruses [59].

The primary objective of this work was to understand the benefits of citizen involvement in the FLAGG community-based surveillance program. We worked with college-aged interns through the internship "Florida *Aedes* Genome Group" (FLAGG) in mosquito surveillance and control efforts, where interns were tested on knowledge and capability of mosquito surveillance. The interns participated in citizen science entomology practices, collected mosquito eggs in urban residential environments using ovitraps and sent photographs and egg papers back to the surveillance team experts for analysis [5, 6, 31, 32, 51].

The impact of the internship was measured by exploring (1) how college-based citizen-science internship increases participants' knowledge and efficacy towards mosquito surveillance, (2) increase participant confidence in science communication and career readiness, and (3) perceived sense of community engagement on or off campus programs. Given abundant information and cues to action on vector borne disease through the FLAGG internship, we hypothesized that (H1) FLAGG participants would be more willing and perceive themselves more capable of participating in mosquito control measures than their non-FLAGG intern and control group counterparts. We also hypothesized that (H2) FLAGG participants would be more confident in professional settings and that (H3) FLAGG participants would have an increased perceived sense of community engagement on campus.

2 Methods

2.1 Consent to participate

Informed consent was obtained from all individual participants included in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Review Board (IRB Protocol #: IRB-22-0068), Florida International University prior to data collection.

2.2 Participants and data collection

Previous Florida *Aedes* Genome Group (FLAGG) participants were identified using contact information they previously provided to the FLAGG internship program. The FLAGG program was a mosquito surveillance and control education internship at Florida International University. FLAGG focused on teaching college students and recent graduates basic mosquito knowledge such as how to differentiate mosquito life stages, how to identify breeding habitats, and were trained on how to use oviposition cups to collect mosquito eggs from their backyards. Other non-FLAGG participants were recruited through biology undergraduate courses and referrals from internship coordinators. Recruitment letters and flyers were distributed to students through email. Students were invited to participate through a qualtrics link and offered either extra credit or community hours. The data collection and incentives protocol were approved by the Florida International University institutional review board (IRB).

This research surveyed three internship experience groups of interest; FLAGG interns (n = 74), non-FLAGG interns (n = 79), and non-interns (n = 159). The FLAGG interns represents a group of students which completed at least one semester of the FLAGG Internship, the non-FLAGG interns represent a group of students which completed at least one semester of an internship program not related to mosquito surveillance or FLAGG at Florida International University, and the non-interns represents a group of students who have never participated in an internship program before. The survey was generated through Qualtrics, and students were recruited by email. Expected survey completion time is 5–10 min. This research evaluates the effectiveness of the FLAGG internship at Florida International University which has served as a community mosquito surveillance program since 2018 and is rooted in South Florida, with most participants being located in the MDC area.

2.3 FLAGG internship program description

The FLAGG internship program's objective was to engage students in hands-on mosquito surveillance activities and collecting of mosquito eggs while providing educational experiences related to the field of mosquito biology and research. As part of the FLAGG internship program, students collected mosquito eggs across Miami-Dade County. At the beginning of the semester, each registered FLAGG-intern received a kit with an ovicup (an oviposition trap which uses stagnant water to attract gravid females), whirl-pack bags (Nasco Sampling/Whirl–Pak), seed papers used for egg collection, and an instruction manual on sampling and surveillance methods. Students set up the ovicups, which are black plastic cups with drainage holes, outside of their residence in shaded locations, weekly, filled them with 200 ml of tap water, and lined the ovicups with seed paper. The ovicups were monitored for three days, after which students collected the seed paper, partially air-dried, and then stored them in whirl-pack bags. These collections were returned to the FLAGG team at Florida International University (FIU) on a monthly basis for the duration of the semester (8–16 weeks).

In addition to the hands-on mosquito surveillance, students were given opportunities to attend periodic presentations throughout the semesters that covered a large range of mosquito surveillance and citizen science related topics, including mosquito biology, genetics, scientific paper analysis, current mosquito-related news, ethics in science, and public health impacts. The topic of mosquito biology covered subtopics such as egg and developmental phase identification, breeding sites, species differentiation, and historical migration patterns. These sessions also introduced students to wet laboratory techniques, including lessons on how to use a microscope for egg counting, for which we offered opportunities for hands-on practice. Lessons also covered applications of the analysis in research. Quizzes related to these topics were offered after each lesson to reinforce student learning as part of their internship experience. These educational activities were scheduled intermittently throughout the internship to provide well-rounded exposure and engagement.

2.4 Variables

Through comparisons of these three groups (FLAGG interns, non-FLAGG interns, and non-interns), program effectiveness was analyzed by assessing differences in the following variables: (V1) willingness to participate in mosquito control and exposure to mosquito control, (V2) knowledge on mosquito abatement, (V3) mosquito abatement behavior competence, (V4) career-related confidence, (V5) perceived academic confidence, and (V6) sense of community engagement on and off campus. The questionnaire focused on student accessibility to experiential education in the form of mosquito abatement internships and whether they help enhance specific student intended learning and personal outcomes. The FLAGG program participant surveys were analyzed to determine what communication goals have been met and which ones should be focused on in future semesters.

For the following variables: (V4) career-related confidence, (V5) perceived academic confidence, and (V6) sense of community engagement on and off campus, the data were prepared where the respondent will answer whether they agree or disagree with a set of questions using a scale coded accordingly. Scales transformed the categorical data into quantifiable data in scales such as: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly agree = 5 [24].

Questions which were grouped into (V2) knowledge on mosquito abatement included questions such as "How confident are you with identifying mosquito eggs?" and "How confident are you with understanding mosquito prevention measures?". The (V3) mosquito abatement behavior competence section included questions such as "On a scale of 1 (Never) to 5 (Daily), how often have you removed empty containers such as tires, flowerpots, birdbaths within the last 12 months to protect yourself and family from being bitten?" The same was asked for a set of 15 mosquito control behaviors and an average score was calculated for each participant.

(V4) career-related confidence was measured using the Vocational Decision Scales that asked students to rate statements such as "My future career is not important to me right now". (V5) perceived academic confidence was established including questions such as their perceived ability to "give a presentation to a small group of fellow students" and "produce your best work under test conditions". (V6) sense of community engagement on and off campus included questions where students evaluated circumstances from "strongly agree" to "strongly disagree" such as "people in this university/neighborhood don't share the same values". This set of questions were asked for on-campus engagement (within the university) and off-campus engagement (within their neighborhoods).

In addition to the structured survey items, FLAGG interns were asked open-ended questions on how they felt about their experiences in the FLAGG internship. These qualitative responses were analyzed using an open coding approach to identify recurring themes and provide a comprehensive overview.

2.5 Scale reliability

The survey section for (1) willingness to participate in mosquito control and exposure to mosquito control, knowledge on mosquito abatement, and mosquito abatement behavior competence, were adapted from a mosquito awareness and prevention campaign in Western Australia [40]. The (2) career-related confidence scale was adapted from the career decision profile revised using the vocational decision scale for college students [22]. The (3) perceived academic confidence scale was adapted from an academic behavioral confidence study in the University of Wales Institute [44]. Lastly, the student's (4) sense of community engagement on and off campus were adapted from the Sense of Community Index (SCI) [3]. All scales were analyzed for reliability using reliability statistics on SPSS, and all showed high reliability, with a Cronbach's Alpha coefficient greater than 0.6 to ensure the scale's reliability [33]. See Table 1 below for the individual scale reliabilities.

2.6 Data analysis

For the three groups of interest, the mean from every group of questions for each individual was used. A one-way Analysis of Variance (ANOVA) on SPSS was run to see if there are any statistical differences between the three internship groups [36] (Table 2). In order to run an ANOVA, the distribution of the data was assessed based on the levene statistic of homogeneity of variance. The samples taken from the populations are independent of each other and do not depend on one another, hence the assumption of independence is met [52].

When the F statistic was significant, Tukey HSD Multiple comparisons analysis was used to compare differences between each pair of groups to detect the source of any statistically significant differences. When there was a significant

Table 1 Reliability statistics for individual scales used

Scale	Cronbach's Alpha	No. of Items
Academic Confidence	0.917	22
Campus Community	0.732	12
Neighborhood Community	0.826	12
Job Confidence	0.793	10
Mosquito Skills	0.943	8
Mosquito Behavior	0.883	16

finding under the test of homogeneity of variances with the Levene statistic, the Brown-Forsythe and Welch tests were then applied and multiple comparisons were tested using Games-Howell. These post hoc tests (Table 3) assessed the mean difference between the FLAGG-interns group and the non-FLAGG interns group, between the FLAGG interns group and the non-interns group, and between the non-FLAGG interns group and the non-interns group. When p-values were lower than 0.05, then the conclusion signified a significant difference in the dependent variable between each group.

3 Results

3.1 Socio-demographic characteristics

A total of 312 Florida International University students participated. There were 312 total participants, 159 which were non-interns and 153 who were interns. The intern group was subdivided to include 74 FLAGG interns and 79 non-FLAGG interns. Most of the participants were female (60%), identified as Hispanic(a) or Latino(a) (80.2%), single (89.4%), spoke Spanish fluently (74.2%) as well English, were born in North America (61.7%), had some college experience but no degree (37.6%), majored in Biology (51.3%), aged 18–24 (79.5%), were employed part-time (35.7%), made less than $10,000 income through personal employment (24.7%), sometimes had difficulty meeting expenses (49.8%), and were not the primary income earners of their household (83.3%).

3.2 Knowledge of and efficacy towards mosquito surveillance and abatement

The survey asked participants to rate their knowledge, attitude and intended behavior around mosquito control. Below are the results comparing FLAGG participants with other interns and non-interns. FLAGG interns were the most likely to participate in mosquito control measures (mean = 4.05), compared to non-FLAGG interns (mean = 3.03) and non-interns (mean = 3.06). The scale went from extremely unlikely (5) to extremely likely (1). The ANOVA analysis generated a p-value of < 0.001.

The majority of FLAGG interns felt they either had "a lot" (21.9%) or "a great deal" (21.9%) of exposure on mosquito knowledge and education, while non–FLAGG-interns mostly felt they had "none at all" (38.8%) and non-interns felt they had "a little" (33.6%). Almost half of the FLAGG interns (47.9%) knew all 4 mosquito life stages (egg, larvae, pupae, adult mosquito) while only 6.7% and 16% of non-FLAGG interns and non-interns did, respectively. Below are the results of comparing the three groups across specific knowledge areas.

3.2.1 Breeding habitats

There was no significant difference in this variable between FLAGG and non-FLAGG participants, and the knowledge was high for all groups. When asked "What environment can become a mosquito breeding habitat?" most students from the three groups answered with responses that included the following keywords: water, hot/warm, household/man-made items holding water, humid, plants, and standing water. 100% of FLAGG students answered with at least one of the aforementioned keywords, whereas only 94.9% and 91.2% of non-FLAGG interns and non-interns were able to answer with the aforementioned keywords, the rest of the students answered with unknown.

Table 2 Summary of major descriptive results

Hypotheses	Non-intern mean	FLAGG mean	Non-FLAGG mean	Total Mean	ANOVA Sig	B-F Sig	W Sig	Results
Mosquito abatement knowledge differs between groups: non-interns, FLAGG interns and non-FLAGG interns	2.707	4.283	2.575	3.036	**0.000**	**< 0.001**	**< 0.001**	**Supported**
Mosquito abatement behavior differs between groups: non-interns, FLAGG interns and non-FLAGG interns	2.552	2.977	2.302	2.587	**0.000**	**< 0.001**	**< 0.001**	**Supported**
Lack of job confidence differs between groups: non-interns, FLAGG interns and non-FLAGG interns	3.270	3.613	3.611	3.436	**0.000**	**< 0.001**	**< 0.001**	**Supported**
Academic confidence differs between groups: non-interns, FLAGG interns and non-FLAGG interns	3.692	3.996	3.936	3.822	**0.000**	**< 0.001**	**< 0.001**	**Supported**
Sense of Community on-campus differs between groups: non-interns, FLAGG interns and non-FLAGG interns	3.630	3.752	3.708	3.674	0.185	0.186	0.179	Not Supported
Sense of Community off-campus differs between groups: non-interns, FLAGG interns and non-FLAGG interns	3.482	3.489	3.321	3.446	0.162	0.189	0.236	Not Supported

Bold indicates significance in the tables

Table 3 Post hoc multiple comparisons

Hypothesis	Test	(I) Group	(J) Group	Std. Error	Sig	95% confidence interval Lower bound	Upper bound
Mosquito abatement knowledge differs between groups: non-interns, FLAGG-interns and non-FLAGG interns	Games-Howell	Non-Intern	FLAGG Intern	0.13022	**<0.001**	− 1.8838	− 1.2682
			Non-FLAGG Intern	0.17536	0.731	− 0.2836	0.5488
		FLAGG Intern	Non-Intern	0.13022	**<0.001**	1.2682	1.8838
			Non-FLAGG Intern	0.17457	**<0.001**	1.2938	2.1234
		Non-FLAGG Intern	Non-Intern	0.17536	0.731	− 0.5488	0.2836
			FLAGG Intern	0.17457	**<0.001**	− 2.1234	− 1.2938
Mosquito abatement behavior differs between groups: non-interns, FLAGG interns and non-FLAGG interns	Tukey HSD	Non-Intern	FLAGG Intern	0.11138	**<0.001**	− 0.6868	− 0.1619
			Non-FLAGG Intern	0.10804	0.055	− 0.0039	0.5052
		FLAGG Intern	Non-Intern	0.11138	**<0.001**	0.1619	0.6868
			Non-FLAGG Intern	0.12889	**<0.001**	0.3713	0.9787
		Non-FLAGG Intern	Non-Intern	0.10804	0.055	− 0.5052	0.0039
			FLAGG Intern	0.12889	**<0.001**	− 0.9787	− 0.3713
Lack of job confidence differs between groups: non-interns, FLAGG interns and non-FLAGG interns	Tukey HSD	Non-Intern	FLAGG Intern	0.09883	**0.002**	− 0.5765	− 0.1110
			Non-FLAGG Intern	0.09666	**0.001**	− 0.5693	− 0.1140
		FLAGG Intern	Non-Intern	0.09883	**0.002**	0.1110	0.5765
			Non-FLAGG Intern	0.11395	1.000	− 0.2662	0.2705
		Non-FLAGG Intern	Non-Intern	0.09666	0.0**01**	0.1140	0.5693
			FLAGG Intern	0.11395	1.000	− 0.2705	0.2662
Academic confidence differs between groups: non-interns, FLAGG interns and non-FLAGG interns	Tukey HSD	Non-Intern	FLAGG Intern	0.08410	**<0.001**	− 0.5028	− 0.1067
			Non-FLAGG Intern	0.08223	**0.009**	− 0.4382	− 0.0509
		FLAGG Intern	Non-Intern	0.08410	**<0.001**	0.1067	0.5028
			Non-FLAGG Intern	0.09752	0.811	− 0.1694	0.2898
		Non-FLAGG Intern	Non-Intern	0.08223	**0.009**	0.0509	0.4382
			FLAGG Intern	0.09752	0.811	− 0.2898	0.1694
Sense of Community on-campus differs between groups: non-interns, FLAGG interns and non-FLAGG interns	Tukey HSD	Non-Intern	FLAGG Intern	0.07128	0.200	− 0.2903	0.0453
			Non-FLAGG Intern	0.06963	0.502	− 0.2420	0.0858
		FLAGG Intern	Non-Intern	0.07128	0.200	− 0.0453	0.2903
			Non-FLAGG Intern	0.08440	0.858	− 0.1542	0.2431
		Non-FLAGG Intern	Non-Intern	0.06963	0.502	− 0.0858	0.2420
			FLAGG Intern	0.08440	0.858	− 0.2431	0.1542

Table 3 (continued)

						95% confidence interval	
Hypothesis	Test	(I) Group	(J) Group	Std. Error	Sig	Lower bound	Upper bound
Sense of Community off-campus differs between groups: non-interns, FLAGG interns and non-FLAGG interns	Tukey HSD	Non-Intern	FLAGG Intern	0.09041	0.995	− 0.2213	0.2043
			Non-FLAGG Intern	0.08831	0.169	− 0.0483	0.3674
		FLAGG Intern	Non-Intern	0.09041	0.995	− 0.2043	0.2213
			Non-FLAGG Intern	0.10704	0.260	− 0.0839	0.4200
		Non-FLAGG Intern	Non-Intern	0.08831	0.169	− 0.3674	0.0483
			FLAGG Intern	0.10704	0.260	− 0.4200	0.0839

Bold indicates significance in the tables

3.2.2 Mosquito control skills

No difference was observed between the non-interns (mean = 2.707) and non-FLAGG interns (mean = 2.575), based on the Brown-Forsythe and Welch tests. The ANOVA analysis generated a p-value of < 0.001, with the FLAGG interns scoring higher than their peers (mean = 4.283) (Table 2). This supports the hypothesis that mosquito abatement knowledge differs significantly between the FLAGG interns and all other participants.

3.2.3 Mosquito abatement behavior competence

Participants of the FLAGG-internship (mean = 2.977) on average scored higher than the non-interns (mean = 2.552) and non-FLAGG (mean = 2.302) interns, respectively. The ANOVA analysis generated a p-value < 0.001, signifying a strong difference between the three groups (Table 2). No difference was observed between the non-interns and non-FLAGG interns. This supports the hypothesis that mosquito abatement behavior differs between groups and is enhanced in the FLAGG group. Specifically, there were differences between FLAGG and non-FLAGG participant on their perceived ability to remove empty containers, use drainage systems for stormwater, use protective clothing, use insect repellent, use pesticides, clean gutters, avoid dusk or dawn hours, avoiding being outside in times of highest mosquito activity, Operating fans, and using automatic mosquito spray/mist. There was no significant difference between the three groups on their perceived ability to hire professional mosquito control services, use a mosquito zapper, use an insect screen/netting, and use mosquito coils.

3.3 Impact of FLAGG on confidence and engagement

Beyond knowledge gained, this study looked at differences between the three participant groups in related feelings and attitudes such as academic and career confidence and engagement in their communities.

3.3.1 Career-related confidence

Non-interns students generally scored lowest (mean = 3.270) when evaluated for job confidence when compared to the FLAGG (3.613) and non-FLAGG interns (3.611). The ANOVA analysis generated a p-value < 0.001, signifying a strong difference between the three groups, (Table 2). Overall, the higher level of job-related confidence in both the FLAGG group and non-FLAGG interns suggest that job confidence is increased by the opportunity of being in an internship.

3.3.2 Academic confidence

Students within the FLAGG group scored the highest in academic confidence (mean = 3.996), and the non-FLAGG interns scored second highest (mean = 3.936). Both significantly differed only against the non-interns group (mean = 3.692). The ANOVA analysis generated a p-value < 0.001, signifying a strong difference between the three groups (Table 2). The FLAGG-interns did not significantly differ from the non-FLAGG interns students in their perceived academic confidence. Overall, the higher level of academic confidence in both the FLAGG group and non-FLAGG interns suggest that academic confidence is increased by the opportunity of being in an internship.

3.3.3 Sense of community engagement

The ANOVA analysis for student levels of sense of community on and off campus generated p-values of 0.185 and 0.162, respectively, suggesting there is no difference between the three groups (Table 2). Although the hypothesis that sense of community on and off-campus differs between groups was not supported, some responses did significantly differ between groups. The students within the non-interns group scored significantly lower (mean = 4.42) than the other two groups (FLAGG intern mean = 4.73, non-FLAGG intern mean = 4.78; p < 0.001) in their intention to remain at the university and their sense of common purpose with classmates (FLAGG mean: 4.09, non-FLAGG interns mean: 3.62, non-intern mean = 3.87; ($p < 0.05$).

3.4 Qualitative comments on benefits of FLAGG

In addition to the closed-ended survey questions, students had the opportunity to provide comments about the benefits of the FLAGG internships. Below is a summary of the main themes that emerged out of the comments.

3.4.1 Bringing course material to life

As STEM skills and knowledge become increasingly required in the workplace, integrating STEM knowledge in a hands-on manner can promote a fundamental shift in student learning [20]. Through the use of FLAGG, students were able to implement their STEM knowledge in a relevant setting as part of a community-based initiative to reduce mosquito presence. The following excerpts represent the students' comments

> "I got to use my biological studies degree to understand the data presented which made it all come full circle with the skills I have had from writing and reading multiple research papers."
> "It helped me attain a better understanding of how my work fit into a larger body of research. This kind of integration of the task with a broader or "big-picture" element helped me understand that research has several layers, all of which are important in their own right."
> "This was a great first involvement in research, where I learned valuable skills like data interpretation, experimental designs, and data collection."

3.4.2 Capacity to educate and increase awareness

University-based citizen science motivates teachers to help raise awareness in varying science fields while encouraging students to engage in the same practices [62]. FLAGG participants were motivated to learn about the dangers of mosquito-borne viruses and potential for disease transmission, leading these students to want to continue to spread awareness in their own communities. For example:

> "I remember always talking about what I learned about mosquito biology and control to my family and friends excitedly, and sometimes I still do! I feel that for a class to make a student do that is truly valuable; It shows that it really made an impact, educated me, which in turn, helped me teach others about it too."
> "The knowledge obtained throughout the experience. It's helpful to apply it to the benefit of my community by creating awareness of the dangerous activities that could increase the number of oviposition sites for these vectors that spread such devastating diseases."

3.4.3 Thinking about graduate school

Sustained engagement in citizen science supports educational learning and can empower participants to enhance their science education [43]. Empowering students and their ongoing education is an outcome we saw in FLAGG students, exemplified by the student comment below.

> "Learning about mosquito control techniques and seeing what graduate students do. As an undergrad, I was unaware that graduate school was something I could do. Being a part of this internship as well as another volunteering activity showed me that I could see myself being a graduate student."

3.4.4 Ability to conduct research in or around home

Being prepared for an inclusive digital platform during pandemic management allowed for the building of trust in a time where the public struggled to have accessible and comprehensible communications with others [55]. Empowering participants was a key focus of FLAGG during the COVID pandemic. The following quotes represent the students' comments.

> "Being able to help and take part in groundbreaking research from the comfort of your own home (collecting the eggs)."

"It was helpful to gain the research experience especially during covid when everything was shut down but the program kept running."

3.4.5 Learning about a public health issue relevant to their community

Community engagement can help increase the local public's sense of ability to participate in raising awareness and environmental surveillance through increased community connectedness and empowerment [58]. FLAGG participants were encouraged throughout their participation to engage with their local community and disseminate the knowledge they learned. Students' comments representing this initiative can be found below.

"I believe that the most important was the knowledge and propagation of mosquitos in my community. In the same way I learned what factors influence more than other."

"…providing information on mosquitoes I learned a lot more about mosquitoes which helped me apply it to my community and to help reduce the attraction of them."

"I really got to know a lot of in depth knowledge about the mosquito species that is prevalent in Florida where I live. Which then helped me spread knowledge on how to reduce populations since you learn prime areas to collect egg and why."

"The strongest portion of the internship was learning the importance of mosquito surveillance & how as a community come together to lower mosquito populations".

4 Discussion

The primary objective of this work was to understand the benefits of citizen involvement in the FLAGG community-based surveillance program. FLAGG students scored significantly better than their peers when asked about mosquito abatement and were more likely to be willing to participate in mosquito control surveillance. FLAGG interns also scored significantly higher in job and academic related confidence when compared non-interns, indicating that FLAGG as an internship offers comparable benefits to students as other internships, reinforcing the value of having accessible internship opportunities. These results indicate that community engagement contributes to participant knowledge, which can influence public perception and effectiveness of mosquito control and protective practices.

FLAGG participants' increased willingness to participate in mosquito control when compared to their non-FLAGG intern counterparts allows for increased mosquito breeding habitat monitoring [50, 57]. To efficiently engage in mosquito control activities, participants need to both learn and be capable of mosquito surveillance, identifying mosquito stages and breeding spots, and in container reduction [12, 17]. FLAGG participants excelled in all the aforementioned activities when compared to their peers. Through these backyard organization and water storage practices, community collaboration can give mosquito control access to private sites otherwise hard to access [28]. The increased surveillance would reduce mosquito population as breeding sites are reduced [57]. This cooperation between students and a mosquito internship gives them the opportunity to gain the hands-on experience of mosquito control practices they need to support mosquito control. Eventually, participants who are experienced and willing can extend their service further by collecting specimens, report their findings, and potentially help analyze collected data [50].

When implemented effectively, a mosquito surveillance program can create an empowered community, as FLAGG has by demonstrating high career-related and perceived academic confidence in FLAGG interns when compared to their non-FLAGG intern peers. Enhancing participant personal development throughout an intern's education can lead to enhancing work-based motivation and reinforcing academic performance [15, 54]. An empowered community can then teach others within the community about the biology and behavior of mosquitoes and the diseases they transmit. Participants can also teach methods of surveillance and source reduction to reduce vector populations and increase disease prevention [63].

As a long-term, hands-on, and low-cost citizen science opportunity, programs like FLAGG generate mobilization towards mosquito control [50]. A great example of this type of integrated and empowering mosquito vector management comes from the largest mosquito abatement program in the United States, in the Lee County Mosquito Control District (LCMCD). LCMCD has successfully generated courses for local funded kindergartens through high schools to teach students basic mosquito biology knowledge and control techniques based on Florida standards of mosquito control [11]. Increasing the amount of community-based mosquito education and participation within MDC is highly scalable and can complement traditional mosquito control to reduce mosquito abundance [34]. By combining hands-on training with community engagement, FLAGG provides an effective model for mosquito surveillance with a flexible framework that can inspire the design of future citizen science internships or programs.

Citizen-involved programs inspire participants to feel comfortable teaching mosquito control practices and prevent misinformation from disrupting public receptiveness of current or novel mosquito control tools [25]. By integrating public input and educating citizens, local agencies could reorient the community to be receptive and even increase public engagement as well as transparency when it comes to mosquito control technologies and methods [46]. FLAGG participants demonstrated improvements in their engagement through their high levels of mosquito abatement behavior, however, it is important to note that our study does not differentiate between the effects of training and other hands-on participation due to the integration of these elements in the FLAGG program design. Future research should aim to design a study where these components are analyzed independently to provide targeted insights into the drivers of their program outcomes. Additionally, future studies should assess public perception of mosquito control and compare it to the perception of individuals partaking in a community-based mosquito control surveillance program. Understanding perception is important, as it can impact the effectiveness of a program in implementing mosquito control practices. Perception of a mosquito program can persuade people to either support or oppose the control tools being used.

5 Conclusion

Studying programs like FLAGG can help us understand how an educational intervention can become a valuable opportunity for both students and professionals as they work together to reduce mosquito populations in peridomestic habitats. The significant higher levels of knowledge on mosquito control achieved by participants in FLAGG led to both desired mosquito control goals and personal development. As programs like FLAGG are implemented, and citizens become more educated, the belief that they are capable of executing specific behaviors and making a difference will increase. This confidence can then translate to a public support of mosquito control measures. The approach used in this study can be implemented in different communities throughout MDC and by different university programs to expand the reduction of vector populations within residential households.

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Data availability The raw survey data are protected and are not available due to potential privacy concerns for research participants. The de-identified data that support the findings of this study are available from the authors upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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