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PlantGIFT: An Effective Teacher Workshop Model for Translating Experimental STEM Research into Hands-on Classroom Activities for Middle and High School Students

Regina Marie Bedgood[a], Sloan Elizabeth Almehmi[a], Katie Busch Chandran[b], James Michael Wyss[b,c], M. Shahid Mukhtar[a,b,d], and Karolina M. Pajerowska-Mukhtar[a,e]

[a]Department of Biology, University of Alabama at Birmingham, Birmingham, Alabama, United States; [b]Center for Community Outreach Development (CORD), University of Alabama at Birmingham, Birmingham, Alabama, United States; [c]Departments of Cell Developmental and Integrative Biology, Medicine and Biology, University of Alabama at Birmingham, Birmingham, Alabama, United States; [d]Department of Genetics and Biochemistry, Clemson University, Clemson, South Carolina, United States; [e]Department of Biological Sciences, Clemson University, Clemson, South Carolina, United States

ABSTRACT

The Next Generation Science Standards (NGSS) advocate for K-12 educators to go beyond teaching content knowledge by prioritizing the integration of academic disciplines into real-life experiences and careers. Schools are now focused on preparing students with the necessary skills and knowledge to succeed in college and careers, and gain exposure to future employment opportunities. Recognizing the significance of collaboration between K-12 teachers and higher education faculty, the National Research Council emphasizes the need for enhanced professional development opportunities. Numerous higher education institutions have rigorous and robust experimental research programs. Additionally, a number of them have established STEM centers, outreach initiatives, and partnerships with local school districts to foster such collaborations. Here, we describe a "PlantGIFT" initiative (Plant Genomics Internships for Teachers), a model that effectively translates university-based research into a week-long professional development opportunity that promotes teachers' ability to understand and teach science concepts in their classrooms. We outline the planning and development stages of the PlantGIFT workshop for secondary science teachers, centered around plant research, including our lessons learned, initial results, and implications for future research and practice.

KEYWORDS

STEM outreach; Plant awareness disparity; Plant blindness; Science education; University partnership; Workshop development

Introduction

Science, Technology, Engineering, and Mathematics (STEM) outreach plays a crucial role in fostering an in-depth understanding, cultivating appreciation, and generating interest in the diverse disciplines encompassed by STEM (Tillinghast et al., 2020). Through such outreach initiatives, educational institutions, organizations, and professionals actively engage with communities, students, and the general public, aiming to showcase their real-world applications. While numerous universities have large outreach programs and initiatives, sustaining successful and long-term engagement with the local school communities can be challenging (Weerts, 2019). In the past decade, new K-12 standards including the Next Generation Science Standards (The National Research Council, 2015) have asked educators to shift their focus from memorization toward connecting content to real-world problems and career opportunities (Alford et al., 2014; Darling-Hammond et al., 2014). Implementation of these standards requires teachers to be comfortable with emerging topics and acquire hands-on experience with newly developed technology and experiments that underlie the research and discoveries. Many educators, however, did not receive sufficient background in these topics in their formal educational training, which substantially limits their ability to deploy the new standards in the classroom (Brown & Bogiages, 2017). Thus, there is a need for professional development (PD) workshops that provide opportunities for teachers to expand their knowledge with new findings, hands-on experiments, and scientific concepts, thus providing ongoing support that allows them to

CONTACT Karolina M. Pajerowska-Mukhtar kmukhta@clemson.edu Department of Biological Sciences, Clemson University, Clemson, South Carolina, United States.

confidently implement science into their lessons and other students-centered activities (The National Research Council, 2015; Brown & Bogiages, 2017). This necessitates increased collaboration between scientists and educators so secondary school teachers can create, select, and become proficient in the required curricula from STEM subject matter specialists (The National Research Council, 2015; Brown & Bogiages, 2017). Universities can serve as effective partners with K-12 schools in supporting efforts to increase college and career readiness (Alford et al., 2014). Here, we discuss an approach to building such a partnership by presenting a model of how a higher education department or research lab can effectively translate real-world research into secondary (6^{th}-12^{th} grade) classroom content. The primary mechanism for partnership is a one-week teacher PD workshop, PlantGIFT (Plant Genomics Internships for Teachers).

Rationale

We propose the PlantGIFT model will be useful for faculty and graduate students from any STEM discipline to assist teachers in their ability to understand and effectively transmit science concepts to their students. PlantGIFT is founded in science, and emphasizes research on genetic modification through Agrobacterium-mediated T-DNA insertion, resulting in the generation of plant mutant lines. It provides training in the wet lab skills necessary to identify genetic modifications, and the role of symbiotic organisms such as endophytic microbes. The workshop is anchored in the problem of Plant Awareness Disparity (PAD), which describes the phenomenon that life science education tends to primarily focus on vertebrate animals as opposed to plants (Wandersee & Schussler, 1999; Parsley, 2020; Parsley et al., 2022; Prokop & Fančovičová, 2023; Marcos-Walias et al., 2023). PAD is composed of four main components: attention (not noticing plants), attitude (disliking plants), knowledge (not realizing the importance of plants), and relative interest (finding plants less interesting than animals) (Parsley, 2020). There is an emerging body of research indicating the presence of PAD in high school students (Yorek et al., 2009; Stroud et al., 2022; Pedrera et al., 2023; Pany, 2014; Marcos-Walias et al., 2023) and even in the major high school biology textbooks used in the United States (Brownlee et al., 2023).

PAD acts as a barrier to students being interested in learning about plants, which in turn decreases interest in and exposure to plants serving as a model for broader scientific concepts like climate change and gene editing. In addition to providing oxygen and raw materials for construction and textiles, plants and other photosynthetic organisms are essential to human survival since they are the main source of food for people. There is an intimate connection between plants and climate change as harsh environmental conditions make it increasingly difficult to grow plants for food. This is such an important issue that the United Nations General Assembly deemed 2020 as the International Year of Plant Health (Sakalian, 2019). Plant awareness is directly and indirectly linked to all 17 of the United Nation's Sustainable Development Goals (Amprazis & Papadopoulou, 2020), and environmental literacy is connected to pro-environmental behaviors (Bissinger & Bogner, 2018). This critical role of plants and lack of adequate awareness has led to decades of calls from the higher education community to prevent the "extinction of botanical education" (Crisci et al., 2020; Hershey, 1993; Marcos-Walias et al., 2023; Stroud et al., 2022). Despite these vital roles and the call for attention and action from thousands of global scientists (Ripple et al., 2019; Armstrong et al., 2023), there is continuing denial of and apathy towards climate change and related problems such as growing enough plants to feed the increasing global population and averting the impeding 2050 food crisis (Bright & Eames, 2022; Oliveira et al., 2019; Schinko, 2020; Stroud et al., 2022; Sakalian, 2019).

As plant scientists, botanists, and environmental educators search for ways to increase student engagement surrounding plants, one thing is clear: the teacher matters. When students are taught by a teacher who is passionate and confident about the topic and effectively engages the students, their learning increases (Bright & Eames, 2022; Jose et al., 2019; Ojala, 2015). Participating in experimental research also increases students' and teachers' knowledge and interest in conducting more hands-on research (Ward et al., 2014). When it comes to topics such as biotechnology and climate change, however, teachers' content knowledge is often not much deeper than that of their students' (Boon, 2010), likely because their own experience with science content was taught with a predominantly human/animal focus and is dated. Finally, the significance of plant-based experimental research cannot be overstated, given its cost-effectiveness, low safety level requirements and ease of implementation in schools.

The purpose of PlantGIFT is to describe an outreach initiative in which a university research lab translated their research into learning opportunities for local teachers, ultimately providing more exposure for teachers and their students to "real science" and "real research", thus helping bring new research, scientific concepts and tools into middle and high school classrooms. The main research question is: how can university researchers effectively translate and disseminate their work to K-12 secondary teachers and students?

In the workshop design, our goal was to enhance and broaden middle and high school science education by introducing plant biology concepts based on our ongoing lab research. This could increase teacher utilization of plant-based laboratory exercises and help form a connection between current science research and student interest in plants, leading to a broader understanding of, and interest in, real-world issues including climate change. PlantGIFT uses *Arabidopsis thaliana*, a safe and cost-effective model organism, to translate state-of-the-art research into a teacher workshop.

Workshop Design

Numerous PD workshops for teachers lack rigorous evaluation, and even in cases where evaluations are conducted, the outcomes often remain unpublished. Among the published ones, a significant portion does not adhere to scientific rigor or standards. While they are deemed effective case studies, they are not considered generalizable models (Darling-Hammond et al., 2017). An examination of 35 PD workshops, acknowledged for rigorous evaluation, revealed the presence of seven themes indicative of effective workshops: (1) content focused, (2) incorporates active learning, (3) supports collaboration, (4) uses models of effective practice, (5) provides coaching and expert support, (6) offers feedback and reflection, (7) is of a sustained duration (Darling-Hammond et al., 2017). Our workshop model was designed around prior workshops conducted by the University's Center for Community Outreach Development (CORD) (Wyss et al., 2013; Chandran et al., 2020). Table 1 shows how the PlantGIFT workshop's elements meet the criteria for this effective design.

Further, to address the phenomenon of PAD, Batke et al. (2020) suggest that educational experiences should 1) improve educator awareness of plants, 2) reduce emphasis on photosynthesis and increase emphasis on plant applications, 3) introduce more hands-on plant exposure (lab or field), and 4) teach more about the application and use of plants. To address the recommendations of both Batke et al. (2020) and Darling-Hammond et al. (2017), we worked to anchor the content, biotechnological applications of plants, and plant genetics, in the context of climate change. We present our generalized model for applying these principles for a science workshop in Figure 1.

Using a theme helped ensure the workshop was cohesive and comprehensive as well as applicable to state-mandated science standards. Teaching through the lens of climate change gives relevant context for, and application of, plant structure and function, genetics, and the scientific method of hypothesis testing.

After establishing a theme, we determined what information from the research lab could be translated into a high school setting. We took into account three major factors: (1) Most secondary science classrooms lack much of the lab equipment found in a research laboratory, (2) The goals of an experiment conducted by Ph.D. students are different than those of a high school student, and (3) Ensuring the experiments and techniques appropriately engage and challenge secondary science students, allowing them to practice experimental science without college-level content knowledge. While our research lab focuses on identifying molecular responses of plants under stress conditions, some of our research questions that could translate to a high school setting include: (1) Are there specific genes that contribute positively or negatively to plants experiencing bacterial infection, heat stress, or drought stress, etc.? (2) Are there microbes associated with plants that help them withstand these stressors? (3) How do these stressors affect plant growth?

Ultimately, we decided to focus on a few experimental protocols including a heat stress assay of young plants, isolation of endophytes (bacteria or

Table 1. Alignment of workshop elements to effective PD workshop elements.

Key workshop element	PlantGIFT workshop structure
Content focused	All lessons and activities anchored in NGSS
Active learning	Participants conducted multiple hands-on labs and modeling activities each day
Collaboration	Participants conducted labs with small groups of peers and developed lesson plans collaboratively
Uses models of effective practice	Workshop modeled from prior effective, long-standing models for teacher PD Labs and lessons modeled best practices for teaching secondary students
Coaching and expert support	Participants conducted labs and under supervision of experienced university faculty and graduate students Experts delivered lectures on their content/research specialty
Feedback and reflection	Participants experienced all activities as learners and then had time to discuss and reflect with peers as experienced practitioner
Sustained duration	Workshop met for 5 consecutive days, 6 hours per day

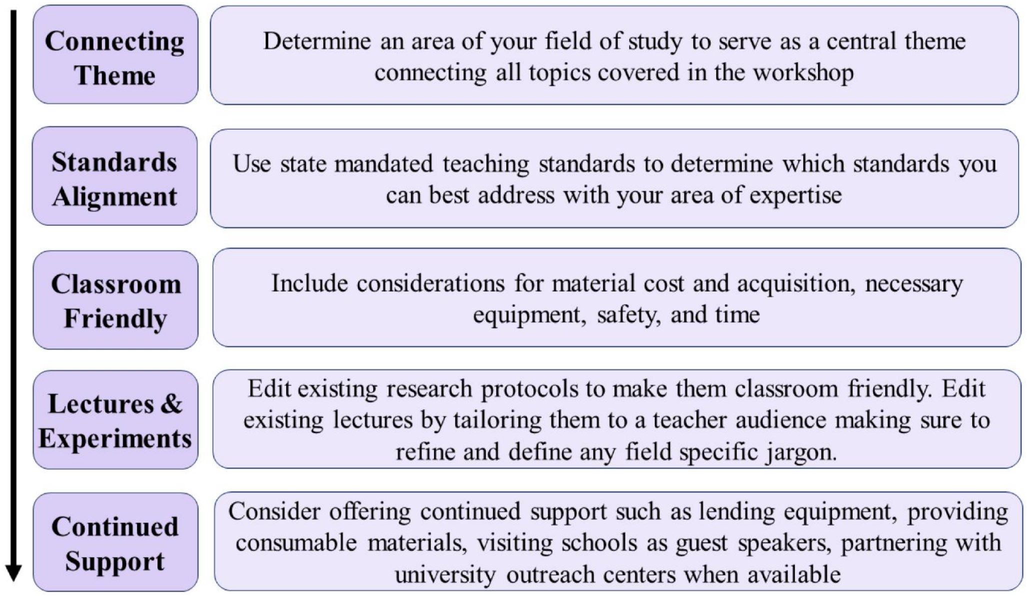

Figure 1. Generalizable model for the process of translating experimental research to a teacher professional development workshop.

fungi that live within a plant) from local plant samples, followed by polymerase chain reaction and gel electrophoresis to identify the genotype(s) of plant DNA samples. Additionally, teachers learned and practiced general lab skills such as using micropipettes, microscopes, gel electrophoresis boxes, plating of seeds, plating of bacteria, preparation of agarose gels, and paper chromatography.

Through our partnership with the institutional Community Outreach Center, we discovered that teachers highly appreciate the chance to gain knowledge from guest speakers affiliated with universities (Wyss et al., 2013). Therefore, this workshop featured presentations from graduate students actively engaged in daily research as well as principal investigators of laboratories. The content covered in these lectures complemented the experiments, thereby enhancing the understanding gained through hands-on activities.

Data Measures

This pilot of PlantGIFT used surveys to collect information about knowledge and skill gains and overall workshop feedback for future development. We learned that while our participants came to the workshop with a range of skills and content knowledge, everyone enjoyed, benefitted from and found value in the experience. These measures did not receive IRB approval in time for the beginning of the workshop; however, we did obtain IRB approval for the use of these measures in subsequent years of the workshop and will report those findings in future studies.

Participants

During the inaugural year of PlantGIFT, 16 teachers registered, and 12 completed the program. Participants came from six districts representing ten schools. A majority of the teachers (83%) possessed 15 years or more of teaching experience. However, only a fraction (27%) indicated feeling comfortable with teaching the lab techniques planned for the workshop prior to attending. Participant recruitment was carried out through email outreach to teachers and school administrators based on the target audience of grade 7+ life, environmental, and AP science teachers. Flyers were sent to all eligible teachers in a 1-hour radius including some individuals having prior engagement in other workshops or outreach programs. Incentives included a stipend upon workshop completion of 100 dollars per day which is comparable to other workshops offered by our institution, graduate-level credit (CEU), and state-approved PD credit essential for certificate renewal. While our institution is in an urban setting, participants were from nearby urban, suburban, and rural schools.

Workshop Structure

PlantGIFT spanned five days, with each day running from 9:00 am to 3:00 pm. It was housed at the local Science Center's teaching laboratory facility (McWane Science Center's GENEius Lab). Each day, two to three main objectives were identified (see Table 2) with corresponding lessons, NGSS alignment, lectures

Table 2. Alignment of workshop activities to next generation science standards.

Day	Topic	Hands-on lab skill	NGSS alignment
1	Plant structures and functions, photosynthesis	Lily dissection	HS-LS1-2
		Paper chromatography of leaf pigments	HS-LS1-5
		Microscopy of leaves, plastids, and vascular tissue	
2	Experimental design, endophytes	Participant design of plant heat stress experiment	HS-LS1-3
		Field specimen identification and collection	HS-LS4-6
		Endophyte isolation and culturing	HS-LS4-3
3	Genetic modification of organisms	Micropipette training and practice	HS-LS1-1
		Agarose gel electrophoresis (preparation of and running gels)	HS-LS2-7
			HS-LS3-1
			HS-ESS3-4
4	Genetic modification of plants via *Agrobacterium tumefaciens* T-DNA insertion	Polymerase Chain Reaction	HS-LS2-2
		Agarose gel electrophoresis of plant DNA for identification of GMO	HS-LS3-2
		Data collection from participants' designed experiments	HS-LS4-5
5	Translating research intro practice	Participant creation of lesson plan based on the week's content	HS-LS2-7

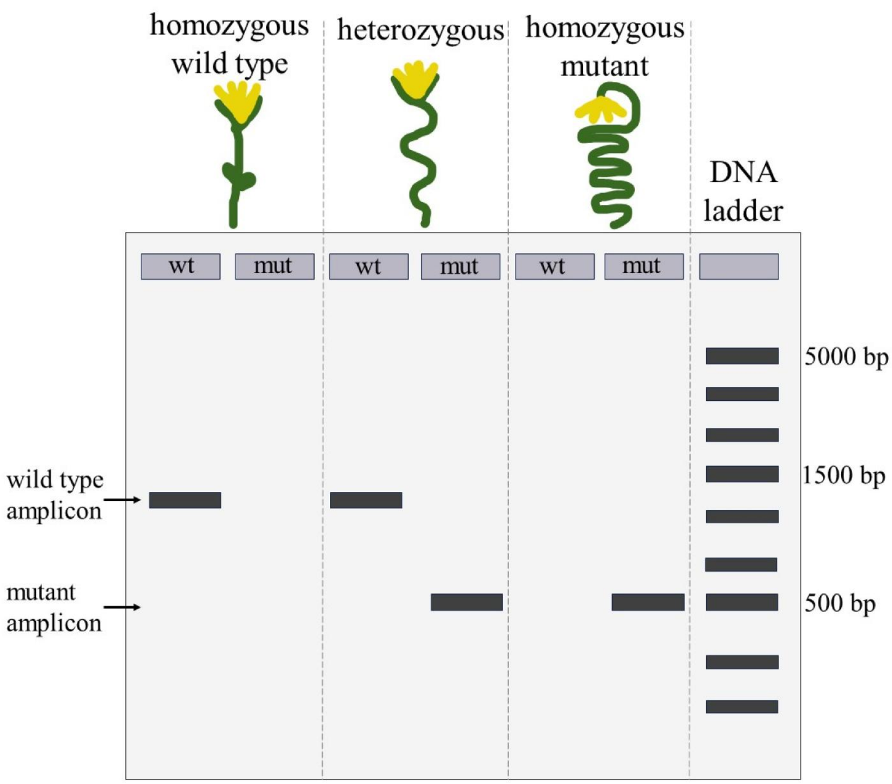

Figure 2. Illustration of DNA electrophoresis experiment and analysis performed by participants.

(30–60 minutes each), experiments, activities, and discussions.

Day 1: The workshop commenced with introductions and icebreakers. The day focused on reviews of plant anatomy, photosynthesis, and training on the proper use of micropipettes.

Day 2: Participants were introduced to the model organism (*Arabidopsis thaliana*) and after a short lecture, designed a heat stress experiment with a partner. Participants conducted fieldwork in a local park to identify plant structures and collected a plant sample. They isolated endophytes from their field samples and prepared agar plates for endophyte growth.

Day 3: Participants continued with the heat stress and endophyte isolation experiment. A graduate student delivered a lecture about Agrobacterium and its use in plant biotechnology. Participants were trained on agarose gel electrophoresis and practiced preparing and running gels with dye.

Day 4: Two lead faculty researchers delivered 50-minute lectures about (1) plant-microbe interactions and (2) plant interdependence with other species. Participants collected and shared final data from their heat-stress experiment. Participants applied gel electrophoresis skills to identify wild type versus mutant plants (See Figure 2).

Day 5: The participants worked in groups to design a lesson plan based on key takeaways from the week. Participants taught their lesson to teen volunteers from our local science museum. The teens provided feedback, giving them insights on what they enjoyed or would like changed. The implementation of the teacher-prepared lesson plans was used as an element in the assessment of the effectiveness of the PlantGIFT.

Teacher Lesson Planning

We believe the effectiveness of PlantGIFT was increased by allowing participants to create a lesson for classroom use. By evaluating their understanding, as well as what they wished to implement in their classrooms, we gained insight for future workshops. Giving participants time for lesson planning and practice allowed them to reflect on and synthesize what they learned, something often overlooked in PD settings despite its importance (Loucks-Horsley, 1996; Darling-Hammond et al., 2017).

Classroom Extensions Post-Workshop

As a part of ongoing support during the school year, participants were offered options of borrowing demonstration materials. Through the State Department of Education via Alabama Science In Motion and Alabama Math and Science and Technology Initiative, most schools/districts have access to necessary lab equipment. We also have a set of portable PCR and electrophoresis boxes available for reservation. We recommend having at least one set of classroom biotech equipment and an online reservation request form. Additionally, members of the workshop teaching team are available to come to their classrooms to conduct experimental demonstrations. A few teachers utilized this resource, further connecting secondary students with graduate students and college-level labs, while providing graduate students more practice with presenting their research in an accessible way. We presented one interactive experiment, Endophyte Extraction, at the NSTA conference in 2023 and encourage others to share lab protocols with science teachers through similar conferences.

Limitations

This workshop did not include pre- and post-surveys of the teachers' understanding of and willingness to teach plant biology. Presumably, teachers who already feel comfortable with the topic or are passionate about it would be more likely to enroll in a content-specific workshop. Specific to plant science, it would be helpful for future studies to examine domains of interest, knowledge, and self-efficacy to determine if the workshop is reaching only teachers who are already interested in plant science or have a specific need to expand their knowledge in this area. It will be important in the future to expand interest to other groups of science teachers, as well, in particular those who are teaching multiple grades (e.g. a 10^{th} grade Chemistry teacher who is expanding their portfolio to 9^{th} grade Biology).

Implications for Practice

PlantGIFT can act as a template for collaboration between teachers and local universities across the country. The teachers in this workshop were vocal about how much they enjoyed the lectures and understandable explanations about the underlying design and mechanisms behind the experiments. Research scientists are accustomed to presenting their research at conferences, in lab meetings, and often teach as part of the requirements for their graduate assistantships, providing support to the students for their graduate training. Thus, these scholars can utilize their current presentations and tailor them to fit the audience of teachers.

Lessons Learned

The PlantGIFT workshop was designed to scaffold content and skills from the broad area of plant biology and focus content on progressive learning by the teachers, so that by the end of the week they were comfortable about introducing the model into their secondary science classroom. This helped to model how content could be introduced in a secondary classroom setting but took away time that could be spent on more complex experiments. Given that any workshop cohort is likely to have a range of prior knowledge and skills, there will be cohorts of teachers who are better served by more introduction and others who are more prepared to dive into higher level skills and content. However, our experience with this workshop indicates that teachers were willing and sufficiently comfortable to jump into complex experiments without needing such introductions. We worked to balance the range of skills by grouping participants with peers who reported similar familiarity levels. This ensured everyone could learn for themselves, rather than defer to the most experienced group member, an important lesson to put into practice in the classroom, in which the teacher strives to have all students engage in the learning.

The teachers reported enjoying the in-depth lectures from experts and hands-on experiments. When preparing presentations, university faculty should consider that they are sharing information for teacher content knowledge and for teachers to take back to use with their students.

The incorporation of lesson planning and implementation gave the teachers a chance to increase their confidence around plant biology while it was fresh on their minds. While not all workshops will have teen volunteers to serve as students, the lesson planning is beneficial to identify potential gaps in knowledge while there is available help.

Conclusions

The PlantGIFT workshop is a model for translating research science to secondary school classrooms. Other universities can use this model to implement plant-science-based professional development workshops for their local communities and school systems. The model can also be extended to other fields of scientific research outside of plant science. The critical elements of our model include creating a unifying theme, aligning content to state science standards, considering what hands-on experiments can be translated from the lab bench to student's hands, including considerations of safety, cost and materials, designing teacher workshops around principles of engaging and effective PD, and continued support following the workshop. As teachers look for real-world content significance and STEM careers exposure for students, a literal and metaphoric opening of lab doors can help to build meaningful pathways to improved STEM education experiences for all students.

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ORCID

Regina Marie Bedgood http://orcid.org/0009-0004-8564-686X
M. Shahid Mukhtar http://orcid.org/0000-0002-1104-6931
Karolina M. Pajerowska-Mukhtar http://orcid.org/0000-0002-5813-7486

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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