# Preparing Teachers to Teach STEM through Robotics

Christina Chalmers

Faculty of Education, Queensland University of Technology

c.chalmers@qut.edu.au

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## Abstract

This paper reports on a university robotics-based education outreach program aimed at building teachers' confidence and capacity, and encouraging students' interest, in Science, Technology, Engineering and Mathematics (STEM). The aim of this study is to examine the perceived value of the outreach program and the professional development (PD) workshops for the teachers participating in the program. The program was underpinned by constructionist theory of teacher PD; constructing knowledge through hands-on activities. The PD workshops focussed not only on how teachers could learn to build and program robots but also how they could develop and implement engaging robotics-based STEM activities in their classrooms. Questionnaires were completed after each workshop and teachers also provided written comments regarding the outreach program. The data collected showed that the hands-on workshops helped the teachers build knowledge and confidence to implement engaging robotics-based STEM activities. The teachers reported the key benefits of partnering with the university outreach program were: the development of their robot building and programming skills; the sharing of ideas for STEM activities to engage their students; and the on-going support provided by the outreach program.

## Introduction

University STEM outreach programs play an important role in addressing the declining rates of student participation and in building their aspirations, as they attempt to attract school students to the STEM fields (Ludi, 2012; Sadler, Eilam, Bigger, & Barry, 2016). This paper reports on a university robotics outreach program, conducted from 2012 to 2016, aimed at raising school students' STEM aspirations and at building teachers' capacity to address the STEM education needs of students from low-SES and regional areas. The program provided resources and professional development (PD) sessions for teachers to build capacity and gain confidence in presenting engaging robotics-based STEM activities for their students. The teacher PD workshops were underpinned by constructionist theory of teacher professional development, focussing on teachers constructing knowledge through hands-on activities in order to provide similar learning activities for their students (Darling-Hammond & McLaughlin, 2011). The PD workshops focussed not only on how teachers could learn to build and program robots, but also on how they could develop and implement engaging STEM activities in their classrooms.

Student enrolments in STEM subjects at secondary and tertiary levels of education are declining (Kennedy, Lyons, & Quinn, 2014). This decline is a concern for universities worldwide as it impacts on students' engagement in higher STEM studies and on their future employment options (Hall, Dickerson, Batts, Kauffman, & Bosse, 2011; Holmes, Gore, Smith, & Lloyd, 2017). Researchers have shown that students from low SES and regional areas are less likely to pursue higher-studies in STEM (Bradley, Noonan, Nugent, & Scales, 2008; Ludi, 2012) and considerable work is being undertaken by universities around the world to raise the aspirations of students from these under-represented groups (Dawes, Long, Whiteford, & Richardson, 2015). By partnering with schools and teachers, universities can help build students' aspirations for future STEM studies and for STEM-related occupations (Education Council, 2015).

A review of relevant STEM education literature highlighted that students were more likely to participate in STEM activities if they had teachers who provided engaging STEM activities in the classroom (Dawes et al., 2005; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011). Robotics has proven to be an engaging tool for motivating students to participate in STEM activities (Ludi, 2012). Robotics has also proven to be an effective tool to engage and stimulate teachers' interest in STEM learning and teaching (Chalmers, Wightman, & Nason, 2014). Robotics-based PD can assist teachers with developing skills in designing, constructing, and programming and with developing an understanding of how constructionist approaches to learning can enhance problem-solving and higher-order thinking among their students (Vollmer et al., 2009).

Based on the philosophy of constructionism, tangible tools can be used to 'think with' in order to explore STEM concepts (Barker & Ansorge 2007; Bers & Portsmore, 2005). The hands-on applications of STEM concepts helps develop 21st century skills, as objects [robots] are constructed to explore and experiment with ideas (Mikropoulos & Bellou, 2013). Teachers can use robotics activities to integrate STEM and incorporate 21st century skills, including creativity (Brahim, Weaver, & Marghitu, 2012), collaboration (Ardito, Mosley, & Scollins, 2014; Yuen et al., 2014), critical thinking (Blanchard, Freiman, & Lirrete-Pitre, 2010), computational thinking (Atmatzidou, & Demetriadis, 2016; Keane, Chalmers, Williams, & Boden, 2016), and communication skills (Nelson, 2012).

Professional development is recognised as a vital component to assist teachers to incorporate 21st century skills and STEM concepts and to enhance the quality of teaching and learning programs in robotics education (Alimisis, 2009; Bers, Seddighin, & Sullivan, 2013; Chambers & Carbonaro, 2003). For example, the goal of Bers, Seddighin and Sullivan's (2013) PD program was to increase teachers' knowledge about robotics, engineering, and programming, as well as the pedagogies for teaching with robotics in early childhood classrooms. Their study found that teachers need support with the technical aspects of working with robots as well as the philosophical aspects of teaching in a constructionist learning environment. The "Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods" (TERECoP) Project (2006-2009) highlighted that teachers are crucial for the successful implementation of robotics in classrooms (Alimisis, 2009). The TERECoP project developed a workshop program using a constructionist approach where teachers constructed programmable robots. The teacher PD course reported on by Chambers and Carbonaro (2003) also used a hands-on constructionist approach where educational robots were viewed as cognitive tools or "Mindtools" that enhanced the teaching and learning process.

Teacher PD programs on robotics education also tend to emphasise the teaching and learning of STEM "Big Ideas" (see Carnegie Mellon Robotics Academy, 2013; Chalmers & Nason, 2017). A "Big Idea" helps makes sense of, or link, numerous concepts or process "into a coherent whole" (Charles, 2005, p. 10). Robotics is a rich context in which to develop mental models and learn STEM "Big Ideas" (Barak & Zadok, 2009); enhancing learning of STEM concepts and processes (Charles, 2005). For example, the Engineering Design Process (EDP) has been used as an organising structure for robotics workshops that integrate STEM (Zeid et at., 2007). The use of "Big Ideas" including friction, ratio, and proportion were used in the design of the Carnegie Mellon Robotics Academy (2013) teacher training course on robotics education. Using STEM concepts and processes can assist students to progress beyond the trial-and-error strategies when working with robots (Silk, 2011). Focussing on "Big Ideas" can also facilitate the meaningful learning of STEM knowledge.

While it is important to focus on STEM "Big Ideas" and 21st century skills, for PD programs to be effective teachers need to also feel confident in their ability to use technology tools in order to adopt them into their classroom activities (Cuban, 2001). A major limiting factor for the successful implementation of robotics activities in the classroom rests in teachers' beliefs in their ability to integrate the technology (Hew & Brush, 2006; Lawson & Comber, 1999). Professional development is essential to make STEM integration sustainable (Wang, Moore, Roehrig, & Park, 2011) and teacher self-efficacy is an important outcome for teacher professional growth (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). Teachers who participate in robotics education workshops show increases in self-efficacy and improved attitudes towards teaching with the technology (Bers, Seddighin & Sullivan, 2013; Stubbs & Yanco, 2009).

Teachers need to be confident with using the technology, know the content they want to teach, and the pedagogical strategies needed to teach the content with the technology (Mishra & Koehler, 2006). Mishra and Koehler's Technological, Pedagogical, and Content Knowledge (TPACK) framework has been adopted by teacher PD initiatives in robotics education (Bers, Seddighin & Sullivan, 2013; Slangen, Keulen, & Gravemeijer, 2011). The TPACK framework highlights that the successful implementation of technology in the classroom depends on the relationship between teachers' technological, pedagogical, and content knowledge. Effective teacher professional development programs with educational robots need to take into account all three aspects (Bers, Seddighin & Sullivan, 2013). Teachers' STEM content knowledge and pedagogical knowledge (on how to teach STEM content) are critical factors for the implementation of engaging STEM activities and for students' active engagement in the classroom (Saxton, et al., 2014). However, despite the importance of teacher education, many university outreach programs fail to focus on teacher training to implement educational robotics (Cejka, Rogers, & Portsmore, 2006; Gibbons & Semich, 2009; Ludi, 2012).

## Robotics Outreach Program

The university robotics outreach program, reported in this study, partners with over 50 schools in low SES and regional areas engaging in robotics activities. The outreach program was designed around a multi-pronged approach to building school students' STEM aspirations and to better prepare teachers to address the STEM education needs of students from schools in low SES and regional areas. The framework involves: (1) providing opportunities for school students from low SES areas to participate in robotics activities; (2) supporting teachers implementing engaging robotics-based STEM activities in their classrooms; (3) providing school-based STEM experiences for pre-service teachers; (4) engaging with parents and communities in order to build support networks for students deciding to pursue further STEM studies.

This study builds on previous research on the university robotics outreach program in which the opportunities for the schools' students and the experiences of the pre-service teachers were examined and reported (Chalmers & Macbeth, 2015; Chalmers, Wightman, & Nason, 2014).

The aim of this study is to determine the perceived value of the robotics outreach program, including the professional development (PD) workshops for the teachers participating in the program (Prong 4).

## Professional Development Workshops

A constructionist approach was adopted for the PD workshops and teachers were actively encouraged to design, build, program, and test their robots (Chambers & Carbonaro, 2003). The design of the workshops focussed on a constructionist approach to learning STEM “Big Ideas” and on the intersecting relationship between technological, pedagogical, and content knowledge. Some of the STEM challenges used in the workshops included:

- Science challenges e.g. collecting data with robot sensors on the ambient light in a room;
- Technology challenges e.g. programming a robot to escape a cardboard city;
- Engineering challenges e.g. constructing a robot to move without wheels;
- Mathematical challenges e.g. measuring wheel circumferences and working out distances the robot will travel.

Four robotics PD workshops were held each year to help the teachers gain confidence and to equip them with the skills to implement engaging hands-on robotics-based STEM activities in their classrooms. The teachers could opt in for the workshops that were relevant to their needs. PD workshops at the beginning of the year focussed on how to use LEGO® robotics kits. In collaboration with teachers, further workshops were developed on how to integrate robotics activities with STEM “Big Idea” lessons (see Chalmers & Nason, 2017). In later years of the program, other robotics platforms and a focus on computational thinking were introduced, based on feedback from the participating teachers. This collaborative planning in school-university partnerships is seen to be effective in fostering a shared understanding of program aims (Gardner, 2011).

The outreach program also provided additional support to the teachers based on their reported requirements including: loan kits; technical advice; activity ideas; assistance with trouble-shooting problems; classroom assistance from pre-service teachers; and facilitating the sharing of program information and lesson ideas via an online discussion forum. Providing additional support is difficult for most PD programs, as the programs are usually short-lived, have no mechanism for ongoing support, and are not embedded in schools (National Academies of Sciences, Engineering, and Medicine, 2015). However, on-going pedagogical support is essential in education contexts where new technologies are being introduced (Reinders, 2009).

In this study, the following research questions were investigated:

1. What is the reported impact of the PD workshops on teachers’ confidence in their ability to implement engaging robotics-based STEM activities in their classrooms?
2. What are the perceived benefits of being involved in the university robotics outreach program for the participating teachers?
3. What do these impacts and benefits imply for the participating teachers, university outreach projects, and teacher educators in robotics education?

## Methodology

The university outreach program and PD workshops were evaluated using a qualitative participatory action research (PAR) approach. Participatory action research is based on qualitative data in order to include the views of the groups involved (Kemmis & McTaggart, 2005). This approach was used in this study in order to discover the perceived benefits of the PD workshops for the participating teachers and to prompt suggestions for improvements to the outreach program. The research approach highlights the collaborative nature of community engagement programs in which participants contribute to the continuous evaluation and improvement of the program (McTaggart, 1991). The study used the PAR approach to evaluate the value of the robotics outreach program and the PD workshops for the teachers participating in the program.

This study followed the PAR cyclical process of planning, acting, observing, and reflecting (Kemmis & McTaggart, 2005). Teachers' comments were taken into account when planning the workshops (Plan). Following their participation in a workshop, teachers were asked to give feedback on their reported confidence in their ability to implement robotics-based STEM activities in their classrooms. This feedback was sought through questionnaires and their written feedback (Act). After completing the workshop the teachers could borrow a set of four robot kits to take back to their classrooms to try out the strategies discussed in the workshop. The teachers observed how the students reacted to the activities and sought support from the program team with any problems or issues encountered (Observe). Teachers' comments were sought at the end of each year of the program asking them to provide feedback and suggestions for improvement to the outreach program and for future workshops. The teachers also reported on their progress in implementing robotics-based STEM activities in their classrooms (Reflect).

### Participants

The participants in this study included all teachers who completed a workshop questionnaire (n=153) and/or provided comments regarding the outreach program (n=145). Teachers' suggestions for improvement were sought through responses to structured statements (see Tables 2-6) and open-ended questions (see Appendix A & B). The teachers were also encouraged to provide written suggestions for future workshops and activity ideas. These data sources are seen as relevant for PAR studies (Burns, 1998).

### Procedure

Following their participation in a PD workshop, the teachers completed a questionnaire regarding their confidence in their ability to implement robotics-based STEM activities. The teachers were asked to respond to statements from strongly agree to strongly disagree, regarding their perceptions of the benefits of the PD workshops. The teachers were also asked to comment on the usefulness of the workshop activities to help engage students in robotics-based STEM activities. At the end of each year, teachers were encouraged to give more detailed responses on the implementation of robotics in their classrooms and provided written comments regarding the value of the robotics outreach program. Ethics approval was obtained for this study and teacher consent was sought before the questionnaires were completed.

## Results and Discussion

The results from this study showed that participating in the PD workshops helped teachers build their confidence and knowledge in developing and implementing engaging robotics-based STEM activities. Table 1 presents the four themes and nine subthemes from this study and highlights teachers' developing knowledge as well as an increased confidence in their ability to implement engaging robotics-based STEM activities.

**Table 1: Research themes and TPACK**

| **Themes** | **Sub-themes** | **Technological, Pedagogical, and Content Knowledge (TPACK) (Mishra & Koehler, 2006)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | CK | TK | PK | TCK | TPK | PCK | TPCK |
| Teacher confidence | Building and programming | X | X | | X | | | |
| | Implementing engaging STEM activities | X | | X | | | X | |
| Teacher knowledge | Teaching strategies for robotics-based STEM | | | | X | X | | X |
| Benefits of outreach program | Aspiration building | | | X | | X | | |
| | STEM Education | X | | X | | | X | |
| | Time to build and program | | X | | | | | |
| | Activity ideas | | | | X | X | | X |
| | Sharing information | X | X | X | X | X | X | X |
| | On-going support | | X | | X | X | | X |

## Teacher Confidence

Previous research has highlighted that teachers are more likely to incorporate robotics activities if they feel comfortable building and programming robots themselves (Cejka, Rogers, & Portsmore, 2006). The PD workshops provided opportunities for teachers to build and program robots and to share pedagogical strategies for implementing robotics-based STEM activities in the classroom. Table 2 highlights the teachers' confidence increased after participating in the workshops. For example, one teacher stated that the workshops had not only advanced their knowledge about teaching robotics but also had *built confidence and enthusiasm as well as given me the willingness to take a risk*. Another teacher commented on their increased confidence in pedagogical knowledge after participating in a workshop, stating that *I feel more confident to incorporate robotics and project based learning across curriculum areas and for a range of year levels*.

**Table 2: Teachers' confidence and ability -PD workshops**

| Statements | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| The workshop has increased my confidence to implement robotics-based activities. | 81 | 70 | 2 | | |
| The workshop has improved my ability to implement robotics-based activities. | 86 | 64 | 1 | | |

The study found that while the teachers reported they were confident with their students' ability to problem solve with robots, their comments showed that they were initially not confident in their own knowledge on how to build and program robots or how to include robots in STEM lessons. Table 3 highlights that the teachers' confidence in their ability to implement robotics-based STEM activities increased due to their involvement in the program.

**Table 3: Teachers' confidence and ability -Outreach Program**

| Statements | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Being involved in the [Outreach Program] has increased my confidence to implement robotics-based STEM activities. | 145 | | | | |
| Being involved in the [Outreach Program] has improved my ability to implement robotics-based STEM activities. | 143 | 2 | | | |

**Teacher Knowledge**

The teachers in this study developed STEM TPCK as they built their knowledge about coding and robotics and about how to facilitate robotics-based STEM activities. STEM PCK is a deep knowledge of the STEM content and how to teach it. With the robotics-based activities teachers needed to develop knowledge about the technology being used (Robots) and the pedagogical strategies needed to implement engaging robotics-based STEM activities (TPCK). For example, one teacher stated that:

> *My knowledge regarding the teaching of robotics continues to evolve on a yearly basis. Having been involved in this excellent program for the last three years, I have expanded my understanding of all areas of programming, engineering, and problem solving*.

Robotics provides many opportunities for STEM education and can increase students' interest in STEM subjects (Chalmers, 2013). Table 4 shows that the teachers agreed, or strongly agreed, that they would be applying what they had learnt from the workshop in their classroom. The teachers' comments focussed on the open-ended tasks used in the workshops and developing new ideas for robotics-based STEM education. One teacher commented that the workshop activities *have been invaluable in engaging staff & students with STEM, both as stand alone activities & embedding it in the curriculum*.

**Table 4: Teachers' application of knowledge -PD workshops**

| Statement | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| I will be applying what I have learned today in my classroom. | 95 | 41 | 2 | | |

The teachers reported that being involved in the robotics outreach program and implementing the robotics activities, introduced in the PD workshops, helped them to motivate and engage their students (see Table 5). One teacher commented that after doing some PD they had become *more aware of how robotics can increase the children's understanding of mathematics, technology and science*. Teachers reported that students' level of engagement increased with classroom activities due to their engagement with the robotics-based STEM activities and this also increased students' interest in STEM subject areas. As one teacher commented:

> *These activities were excellent in engaging our students in Science, Technology, Engineering and Mathematics subject areas. Students were highly motivated to be involved and as a result the learning which occurred was highly effectual, rewarding and enjoyable. The variety of concepts covered as a result of this involvement is also very comprehensive*.

**Table 5: Students' engagement and interest -Outreach Program**

| Statements | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Being involved in the program has increased students' level of engagement with classroom activities. | 76 | 46 | 9 | | |
| Being involved in the program has increased students' interest in STEM studies. | 85 | 39 | 8 | | |

The program partnership with schools, teachers, and the university outreach program helped build students' aspirations for future STEM studies and for STEM-related occupations. For example, one teacher reported that the robotics program was being implemented at their school and was helping foster students' tertiary study aspirations and stated that *not only is the robotics program at school used as an extra curricula gifted and talented extension program, it doubles as a university encouragement tool in a low socio-economic area.*

### Benefits for Teachers

The teachers reported the key benefits of being involved in the university outreach program as: developing ideas for teaching robotics-based STEM activities; having time to develop their own robot building and programming skills; sharing information with other teachers; and the on-going support provided by the pre-service teachers and outreach program staff (see Table 1).

Intensive professional development programs with robotics can transform teachers' ideas about teaching and learning, as well as their teaching practice, by introducing them to a more learner-centred approach (Slangen, Keulen, & Gravemeijer, 2011). The teachers in this study showed that they were willing to embrace a more hands-on, learner-centred approach and to learn with their students. Table 6 shows that overall the teachers were satisfied with the quality of the workshops. For example, one participant stated that *the workshops were fantastic! They opened my eyes to the endless educational applications of robotics and the 'hands on' nature*.

**Table 6: Teachers' overall satisfaction -PD workshops.**

| Statement | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Overall I am satisfied with the quality of today's workshop. | 110 | 39 | 4 | | |

This willingness "to take the journey" is important, as learning with new technologies requires teachers to be active in the learning process; learning through the same methods they will be using with their students (Darling-Hammond & McLaughlin, 2011). During the hands-on workshops, the teachers had time to explore robot design, construction, programming, and to develop their STEM ideas for taking into the classroom. One teacher stated the workshops had provided *more time to explore programming with the robots - more time to play for myself.*

Many teachers in this study commented specifically on the benefits of the on-going support provided by the pre-service teachers and outreach program staff. For example, one teacher highlighted that the support *has helped us make it a major school event with positive outcomes for students. It has also supported me in my busy curriculum, to help provide the extra curricular lessons*. Another teacher stated that the available support was the most helpful aspect of the outreach program. The on-going support provided by the university outreach program enabled the teachers in this study to develop deep knowledge about robotics and STEM education over the course of the program as indicated in the following comment:

> *One of the most helpful aspects of the Robotics program was the amount of support that both myself and my school were provided throughout the year. Anytime I required help with something a representative was available to assist me.*

## Conclusion

Building teacher capacity is integral to improving student participation in STEM higher education (Education Council, 2015) and robotics is a great way to get students engaged and excited about STEM topics (Chalmers, 2013). By building teachers' knowledge and confidence they can deliver engaging robotics-based STEM activities in their classrooms. The teachers in this study perceived that being involved in the university robotics outreach program had enabled them to build their knowledge and confidence, had helped motivate and engage their students in the classroom, and inspired students' future STEM study and career aspirations. The results from this study informed the outreach program's four-pronged framework described in this paper. While this study focussed on building teacher capacity, future research will further unpack the framework and the implications for other university STEM outreach programs, and for teacher educators in robotics education. The framework provides a system for planning and implementing strategies for a sustained outreach program that focusses on building school students' STEM aspirations and on preparing teachers to address the STEM education needs of students from schools in low SES areas.

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## Appendix A

## Workshop Questionnaire

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Not Applicable |
|---|---|---|---|---|---|---|
| The workshop has increased my **confidence** to implement robotics-based activities | | | | | | |
| The workshop has improved my **ability** to implement robotics-based activities | | | | | | |
| I will be applying what I have learned today in my classroom | | | | | | |
| Overall I am satisfied with the quality of today's workshop | | | | | | |

Has your knowledge of teaching robotics in the classroom advanced as a result of attending this workshop? Please provide an example.

If you teach robotics, or incorporate robotics in your classroom, will your experience today change the way you teach robotics? Please provide an example.

What difficulties have you encountered when implementing robotics education in your classroom? Please explain.

What successes have you encountered when implementing robotics education in your classroom? Please explain.

What support would suggestions do you have for improving this workshop or for future workshops?

Thank you for completing this questionnaire

# Appendix B

## Outreach Program Questionnaire

Which robotics activities were you involved with?

| | |
|---|---|
| Loan kits | ☐ |
| Competitions | ☐ |
| Teacher Professional Development | ☐ |
| Fun days | ☐ |
| Exhibitions | ☐ |
| Displays | ☐ |

Please comment on the usefulness of these activities to help engage students in robotics-based STEM (Science, Technology, Engineering, and Mathematics) activities

Which Robotics activities are you are involved with at school?

| | |
|---|---|
| Class lessons | ☐ |
| Afterschool or lunchtime club | ☐ |
| FLL | ☐ |
| Robocup | ☐ |
| Displays | ☐ |
| Exhibitions | ☐ |

Please comment on the usefulness of these in-school activities to help engage students in robotics-based STEM (Science, Technology, Engineering, and Mathematics) activities

| *Please tick the most appropriate response* | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Being involved in the [Outreach Program] has increased my confidence to implement robotics-based STEM activities | ☐ | ☐ | ☐ | ☐ | ☐ |
| Being involved in the [Outreach Program] has improved my ability to implement robotics-based STEM activities | ☐ | ☐ | ☐ | ☐ | ☐ |

In what ways has your knowledge about the teaching of robotics advanced as a result of your involvement in the [Outreach Program]?

In what ways has your knowledge about, and perceptions of robotics changed as a result of your involvement in the [Outreach Program]?

About your students

| *Please tick the most appropriate response* | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Being involved in Robotics activities has increase students' level of engagement in classroom activi | ☐ | ☐ | ☐ | ☐ | ☐ |
| Being involved in Robotics activities has increase students' interest in STEM studies | ☐ | ☐ | ☐ | ☐ | ☐ |

Please comment on successes or difficulties you have encountered while being involved in the [Outreach Program].

Please provide suggestions for additional support you would like to receive

Please provide suggestions for improving the [Outreach Program]

Any further comments

Thank you for completing this questionnaire