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The Effective Diffusion of Educational Robotics in Rural Areas: A Case Study in the Sakha Republic of Russia

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Abstract: The purpose of this study was to find the determinants of effective diffusion of educational robotics in rural areas. The study analysed the key components, difficulties, and major lessons of the successful case of the remote northern region of Russia – Sakha Republic. The study used a mixed-method approach consisting of interviews, survey, literature analysis, and participants' observation. In the survey participated 57 robotics teachers and 113 elementary, middle, and high school students of the Sakha Republic. From survey participants were randomly chosen 30 robotics teachers and 18 middle and high school students for the interview. The literature analysis explored reports and articles on the educational robotics activities in the Sakha Republic for the period of 2011-2018. Based on the findings, the study developed a process model with five principles and ten components that influenced educational robotics diffusion in the Sakha Republic. One of the main determinants of the model was a support system of public-private partnerships and a local community of educators. Another was the need to consider the local area's constraints, possibilities, and culture when implementing any technology in the rural region's education. In the researched case two major determinants would not be possible and sustainable without strong leadership. The findings showed that strong local leadership could use knowledge of the local area to provide more appropriate solutions and could build the active support of the local community and public-private partnerships that would accelerate the diffusion of technology in the rural region's education.

Keywords: *Educational robotics, innovation diffusion, rural education, ICT4D.*

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Introduction

With expansion of the use of modern technology in education and predictions for increasing digital inequality, there is a pressing need for researchers to investigate these issues in rural areas (Avery, 2013; International Telecommunication Union - Telecommunication Development Sector [ITU-D], 2017; Leonard et al., 2016; Rodriguez & Najera, 2015). While remote regions have challenges that can complicate the implementation of modern technology in education, there are some successful cases. To demonstrate the possibility of successful modern technology diffusion in the educational sector in rural areas, the authors selected the Sakha Republic, an extremely remote region of northern Russia, for analysis. The Sakha Republic's educational model has successfully initiated a local-oriented, bottom-up scheme for educational robotics diffusion that was sustainably developed over eight years without significant investment. The region is one of the early adopters of educational robotics in Russia, beginning in 2011 and continuing with the efforts of the Small Computer Academy (SCA), North-Eastern Federal University (NEFU). Throughout the past eight years, the SCA managed to involve 29 districts (out of 34) of the Sakha Republic in the usage of educational robotics and conduct annually ten regional and four regional stages of national robotics competitions with the participation of about 100-300 K-12 students and teachers in each event (North-Eastern Federal University, 2019).

The Sakha Republic is the largest Russian region with a landmass of 3,084,000km^2, and due to its severe natural and climatic conditions, it has a low population of just 967,009. Approximately 71.3% of schools in the Sakha Republic are located in isolated, rural areas that are separated by distances of up to 550 km (Government of the Republic of Sakha (Yakutia), 2019). Since it faces similar challenges as other remote regions but exemplifies a more extreme case, it was selected for this study to demonstrate if it is possible to implement educational robotics in such an exceptionally remote region. If so, then not only is the implementation of other technologies possible, but similar (perhaps easier)

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steps can be executed in other rural areas as well. Moreover, the case of educational robotics diffusion in the Sakha Republic has generated interest because it is not an ordinary implementation process with simple provisions, like equipment and teacher training.

The objective of this study was to find determinants and key components for the successful diffusion of educational robotics in rural areas. The paper argues that success is determinant on localization, which considers local people's needs and an area's limitations and potential. To address this aim, the study involved an in-depth analysis of the Sakha Republic's educational robotics diffusion with the following research questions in mind:

(1) What were the key components of the successful diffusion of educational robotics in the Sakha Republic?

(2) What were the difficulties of implementing and diffusing educational robotics in the Sakha Republic?

(3) What major lessons could be derived from the diffusion process of educational robotics in the Sakha Republic?

Literature review

Implementing educational robotics in rural areas: Needs and constraints

The fourth industrial revolution increased the need for a change in educational systems, especially expanding the utilization of modern technology (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2018). For rural areas, the fourth industrial revolution has caused even more digital inequality, so it is crucial to bring modern technology into remote educational practices (Schwab, 2017). These areas face challenges (e.g., significant geographical distances, small populations, and low socio-economic status) which affect educational quality, such as low student-teacher ratios, inadequate infrastructure, lack of quality teachers, scant funding, low level of awareness concerning the benefits of modern technology, and limited educational offerings (Echazarra & Radinger, 2019; International Telecommunication Union - Telecommunication Development Sector [ITU-D], 2017).

In their studies of Asia and the Pacific, Ra et al. (2016) explain that the gap in the use of technology in education between developed and developing countries is due to socioeconomic status, and, most importantly, poor educational planning, underinvestment and misallocation of resources, and this means that the target area was not a focus. Gulbahar and Guven (2008) recommend that when developing countries adopt technology, it should easily fit into the current educational system, be accessible to the target area, and it should not be costly to implement. Thus, it is important to understand and identify the needs of the target area and the groups involved.

Among all the modern technology options available, this study selected educational robotics since it is an advanced and unique interdisciplinary tool that combines science, technology, engineering, and mathematics to effectively facilitate Science, Technology, Engineering and Mathematics (STEM) education (Eguchi, 2017; McKenna et al., 2018; Mubin et al., 2013; Kirikkaya & Basaran, 2019; Rusk et al., 2008). Educational robotics create an entertaining and engaging hands-on learning environment (Barker & Ansorge, 2007; Eguchi, 2017) by enhancing soft skills, such as critical thinking, problem-solving, communication, leadership, teamwork, and creativity (Alimisis, 2013; Altakhayneh, 2020; Barker & Ansorge, 2007; Eguchi, 2017; McKenna et al., 2018; Nugent et al., 2010). One of the main factors that prevents the implementation of educational robotics, particularly in remote schools, is that it tends to be perceived as too advanced and expensive. The belief remains that more equipment needs to be provided for the successful implementation of educational robotics and any modern technology. The need for equipment provision and training for teachers was only relevant when the technology was still in the early stages of introduction to the education sector (Bingimlas, 2009; Pelgrum, 2001), but now it is a secondary issue. Currently, the primary issue concerns the sustainable and quality diffusion of technology that can be utilized in classrooms, especially in rural schools. As one study noted, "Just filling schools with the necessary Information and Communication Technology (ICT) neither improves the quality of instruction nor creates more effective learning environments" (Gulbahar & Guven, 2008, p. 38).

When effectively adopting educational robotics, according to Sang et al. (2010) and Scherer et al. (2015) it is important to focus on understanding the operators (primarily teachers) and what motivates them to use technology by considering factors such as culture, gender, and thinking processes. Scherer et al. explain that this helps to identify the specific needs of the operators and the reasons for integrating and utilizing technology in a classroom setting. It is also important to consider that in developing countries, according to Ra et al. (2016), qualified teachers are lacking and many demotivated teachers must work on large classes. They also have a highly limited career path with few opportunities for professional development. Therefore, this study focuses on analyzing a local area-oriented diffusion process of educational robotics in remote areas.

Introducing innovation in education: The importance of the diffusion process

The implementation of any technology in education is usually supported by a large investment that is based on the literature, but this does not always guarantee implementation by the schools or that it will be utilized and integrated by the teachers in the classroom. A need to understand the diffusion process is required in order to acquire the technology, adapt to it, and spread innovation within organizations. According to Carr (1999), there are two traditional approaches to technology diffusion—top-down and bottom-up. While the top-down diffusion approach provides stability in administrative sponsorship, the bottom-up approach has no specific steps for diffusion nor a guarantee of its success. Although, as Carr points out, the impetus for innovation diffusion begins with individuals and their communication, which means that a bottom-up adoption has greater potential to succeed.

Similarly, Fagerberg et al. (2006) book Network of innovation. The Oxford Handbook of Innovation says that people play an important role in successfully diffusing innovation based on several determinants of diffusion rate. The first is the consumer benefit received from the new technology, and the second is the network effect where a consumer's quick adoption of the new technology is due to other consumers using it. Moreover, the adoption of technology is heavily reliant on its cost. Another determinant is how well it benefits the consumer's needs. Fagerberg et al. suggest that the market size, industry environment, market structure, and cultural and social determinants also influence the diffusion process.

This study's focus is to understand the implementation and the decision and persuasion determinants involved, which are best described by Rogers' (2010) theory of the diffusion process and suggests several factors that contribute to the adoption or rejection of innovation. Rogers' theory highlights four main elements in the diffusion of innovation theory: (1) innovation, (2) communication channels, (3) time, and (4) the social system. To reiterate, the role of people and their communication can be observed in each element. Rogers (2010) explains that the innovation factor, for example, is when an idea, practice, or object is perceived as new by an individual based on the determinants of its adoption, such as knowledge, persuasion, and decision-making. Thus, according to Rogers, the determinants of innovation diffusion begin by answering the following questions: What is the innovation being referred to? How does it work? Why does it work? What are its consequences? What will its advantages and disadvantages be in my situation?

The exchange of innovation information is achieved through a communication channel, which Rogers (2010) defines as mass media and interpersonal channels. Rogers' innovation-decision process model (2010) observes that one of the important aspects of the diffusion process is the element of time for decision-making about adopting or rejecting an innovation. This model explains and measures the speed of adoption by characterizing the innovation, adopters, and environment. The last determinant for the adoption of innovation concerns a social system, explained by Rogers as a set of interrelated units that are engaged in joint problem solving to accomplish a common goal. Rogers sees that the social structure, system norms, opinion leaders, and change agents play important roles in the diffusion of innovation, as they help to suit individuals' norms and needs for adoption.

The diffusion of educational robotics in the Sakha Republic

In Russia, Presidential Decree No. 899 on July 7, 2011 required that schools match societal needs by preparing their graduates to pursue natural and technical sciences. In 2014, robotics was added to the list of priority areas for technological development within the framework of the "Strategy for the Development of the Information Technology Sector in the Russian Federation for 2014–2020 and the Future to 2025" (Ospennikova & Ershov, 2015).

Despite remote geographical challenges, due to the active promotion by a subdivision of the NEFU, the SCA, the Sakha Republic became an early adopter of educational robotics in Russia. As part of the university, the SCA played a key role in diffusing educational robotics to schools, centers, and institutions in the Sakha Republic. Throughout the past eight years, the SCA has been actively promoting educational robotics in twenty-nine districts (out of thirty-four) in the Sakha Republic, and they also implement robotics in schools. In Russian and international robotics competitions and contests, students demonstrate progressive achievements. They also actively participate in the SCA's robotics events, which holds twenty-three on-site and online robotics events annually.

The SCA's goal is to introduce modern technology to pre-K, K–12, educators, and university students. Its focus is on career guidance, as it is an organization where students participate in educational and research project activities and develop methodological support for teachers. Their activities can be categorized into three groups: educational, international, and organizing robotics competitions and contests. The educational activities of the SCA are robotics courses for pre-K, K–12, and university students and training courses and seminars for educators. The SCA also visits the Sakha Republic's rural districts to conduct seminars and robotics training for both students and teachers. Since 2013, the SCA has conducted robotics seminars in other Russian regions as well, including Anadyr, Khabarovsk, Yuzno-Sakhalinsk, and Vladivostok (North-Eastern Federal University, 2019).

Since the SCA began preparing and conducting robotics competitions and contests in 2013, a greater number of schools have begun implementing educational robotics in the Sakha Republic. In addition, the number and variety of competitions and contests have increased, so these events have become one of the primary components in the SCA's field. The SCA is the official organizer of the regional stage for Russian robotic festivals, such as RoboFest and Robot Olympiad as well as Russian competitions, like IKAR and IKaRenok in the Sakha Republic. Furthermore, it organizes and designs the Republic's robotics competitions and creative contests across long distances and on-site (North-Eastern Federal University, 2019).

The third primary activity of the SCA involves international cooperation, and since 2011, one of the main annual international activities of the SCA has been the International Summer School on IT and Robotics. As a member of the APEC [Asia-Pacific Economic Cooperation] Learning Community Builders (ALCoB),† the head of the SCA has other international partners as well, which opened up the possibility for organizing the Sakha Republic's schools and university students to participate in international camps, competitions, and other educational events, while also sending professors and teachers to train (North-Eastern Federal University, 2019).

Besides the SCA, other centres in the Sakha Republic also provide classes on robotics. For example, in 2012, the Sakha Republic's government opened robotics classes in the Junior Science Academy and the Republican Resource Centre called "Young Yakutians." Since 2013, robotics classes have appeared in the Centre for Technical Creativity in Yakutsk, and in 2017, the Children's Technopark, Kvantorium opened. Other private centres also began operating in 2014, and the first of these was the ANT Training Centre, which is franchised under the LEGO company. Another private centre called, My Robot Children's Robotics Club, is a franchise of the Russian company, Brain Development. In all of these centres (aside from My Robot Children's Robotics Club), robotics is not the main learning activity. Small private and government-affiliated canters and schools also provide robotics classes, but they are challenging to track. However, robotics is not their priority, and these centres do not last very long in the market.

Methodology

Research design

To address the objective and gain an in-depth understanding of the Sakha Republic's educational robotics diffusion process, this study has conducted a mixed-method analysis (Teddlie & Tashakkori, 2003; Creswell & Clark, 2017). First, a qualitative literature analysis established an understanding of educational robotics diffusion in rural areas in the Sakha Republic. Then a survey was used to determine students' and teachers' perceptions. To verify and comprehend the data, teachers and students, as well as the head of the NEFU SCA was interviewed. Moreover, since one of the authors of this study has been deeply grounded in her first-hand experiences at the NEFU SCA over the past eight years, a participant observation analysis was used to discover hidden issues and reveal greater understanding. To validate the findings, each data collection tool's results were crosschecked with each other and verified with the expert on educational robotics in the Sakha Republic.

Data collection tool

Qualitative literature analysis

The qualitative literature analysis was used to answer the first research question on key components of the successful diffusion of educational robotics in the Sakha Republic. The analysis explored reports and official publications of the Ministry of Education of the Sakha Republic, reports, presentations, and articles on the SCA's activities that could be components that influence education robotics diffusion in the Sakha Republic from 2011. Each publication was assessed for eligibility to the first research questions with relevant analysis, verified data, and/or appropriate methodology.

Survey

The survey was used to explore teachers and students' perceptions on robotics diffusion in Sakha Republic's education at the beginning and present. This study conducted three pilot surveys of teachers and students to test the initial set of questions. The questionnaire aim was to access the diverse experiences and to ensure that the questions included all aspects of educational robotics diffusion. Three pilot surveys were conducted during three different robotics events in the Sakha Republic on January and February 2018. Pilots helped to develop a questionnaire that supports the understanding of the educational robotics diffusion process. The final survey was conducted from March 24 to 25, 2018, at the VI Republic Robotics Festival, Roboti Ongor-Tang-Salay (RobOTS) to survey participants of various robotics experiences from all over the Sakha Republic. In the survey participated 113 students (4th–11th grade) and 57 K–12 teachers from the Sakha Republic.

The questionnaire consisted of multiple-choice, open-ended, and Likert-scale questions regarding their opinions and experiences with educational robotics from the beginning up until the time of the festival. The teacher survey was a

† ALCoB is one of the leading educational human networks in the APEC region. ALCoB consists of APEC member economies' leading educational teac hers, learners, supporters, education administrations, and scholars. ALCoB activities promote educational collaboration and focus on narrowing the A PEC region's digital divide.

questionnaire with twenty-two questions about educational robotics experience and eleven questions based on Rogers' (2003) innovation-decision process with its five elements (i.e., knowledge, persuasion, decision, implementation, and confirmation). The student survey was a questionnaire on robotics classes, which consisted of eleven questions. Six of these questions were similarly based on Rogers' (2010) innovation decision process.

Interview

Interviews on educational robotics diffusion in the Sakha Republic were also conducted during three pilots. Interview answers were analysed and reflected to elaborate and improve the final questionnaire. The final interviews were conducted from March 24 to 25, 2018, at the RobOTS festival. All interviews were recorded on the phone and further written as a script for analysis. The interviewees included a total of thirty robotics teachers and eighteen students from middle school to high school (5th–11th grade). All respondents participated in the survey and were randomly chosen during the RobOTS festival. In addition, a separate interview with the head of the SCA was conducted before the RobOTS festival.

The interview questions were related to the survey questions previously disseminated, which was necessary for validation and an in-depth understanding of the answers. The interview consisted of twenty-three questions about basic information concerning the interviewee and their experience with educational robotics from the beginning until the time of the interview. Eleven questions were based on Rogers' (2010) innovation decision process, and three questions concerned the current situation of educational robotics in their district (Sakha Republic).

Data analysis

The analysis started with a content analysis of the literature and interview with the head of the SCA, which results were interpreted by using four elements of Rogers' diffusion of innovation theory framework: 1) innovation, 2) communication channels, 3) time, and 4) social system. These four elements were used to outline the educational robotics diffusion process in the Sakha and its key components. The focus was on the SCA's activities that could influence schools to implement education robotics.

The findings of the literature analysis and interview with the head of the SCA were a base for the questions of surveys and interviews. To develop questionnaires that show the diffusion process, the survey and interview questionnaire were tested on three pilots. The questionnaires ensured to consider all aspects of educational robotics diffusion based on Rogers theory as well as different perceptions and experiences of respondents. The survey and interview answers were analysed used cross-tabulation with such categories as years of students' starting learning and teachers' years of starting teaching robotics, students' age, teachers' subjects, and types of schools (rural or urban). Those categories were used to find the differences and commonalities in their answers depending on when they introduced to robotics, their background, and where their school is located. The results of literature analysis, survey, and interviews were also crosschecked between each other to validate the findings. Those finding commonalities helped to highlight ten key components that influence the successful diffusion of educational robotics in the Sakha Republic.

The literature, survey, interview, and observation results were also used to outline the main issues and causes by using the fishbone analysis of Kaoru Ishikawa. The fishbone analysis was used to explore the main issues SCA, students and teachers faced in the diffusion of educational robotics in the Sakha Republic, its causes and relationships. Those results were divided into two fishbone analysis of educational robotics diffusion situation in the Sakha Republic in 2011 and 2018 to identify and compare the situation of early and later adoption. Outlined major issues were grouped into seven categories, where the sequence of issue categories ranges from the most to the least important issues depending on the implementation process in 2011 or 2018. For each category were found relevant sub-issues and possible causes.

Qualitative and quantitative findings were used to develop a process model of SCA's influence on educational robotics diffusion based on John M. Keller's ARCS (Attention, Relevance, Confidence, and Satisfaction) model. The ARCS model was a base to understand how motivation is encouraged. Thus, this study identified four principles that SCA used to influence education robotics diffusion motivation. This study also revealed stakeholders' involvement in diffusion through onion ring analysis.

Findings / Results

RQ1: What were the key components of the successful implementation of educational robotics in the Sakha Republic?

The qualitative literature analysis showed that the SCA was the first to introduce and provide an impetus for educational robotics diffusion in the Sakha Republic, and so it was important to have a detailed analysis of the SCA's activities. Based on the findings from the literature analysis and verification with survey and interview results, this study found ten key components of the SCA's activities that influenced schools and educational organizations to implement education robotics: (1) short-term, on-site training for teachers and students in local areas; (2) localized and adapted robotics competitions; (3) public-private partnerships (PPP); (4) international cooperation; (5) future local professionals' training; (6) adapted teachers' training courses; (7) the participation of Pre- and K–12 students in all activities; (8) local community development; (9) ensuring the appropriateness of the local area, robot type, or solution; and (10) strong leadership.

A major activity in educational robotics promotion was SCA staff visits (including SCA's head) to the Sakha Republic's remote schools to organize short-term robotics training courses. This stimulated rural schools to reconsider their opinions on educational robotics, especially in administration. In an interview, a teacher who had come from the furthest district claimed that their primary challenges include high transportation fares, low learning possibilities, low speed or absence of the Internet, budget shortages for buying robotics sets, as well as sending teachers to participate in training courses. However, some of these issues could be overcome with the school administration's support. A teacher explained, "After the SCA visit, our school administration decided to invest in buying a couple of robotics sets as well as sending me to teacher training courses and later with some students to participate in robotics competitions." In addition, 17 out of the 30 teachers interviewed had said that they have been trained and/or consulted with SCA on educational robotics and admitted that the SCA experts school visits were an impetus for their school administration to have a positive opinion on educational robotics as well as an increase of student interest and teacher's confidence on learning and teaching robotics. The SCA also used localization when adapting teacher training courses by considering the situations of local schools, such as a lack of robot sets, students' cultural differences, and slow Internet speeds.

The SCA introduced the best practices to Sakha teachers in order to illustrate various methods and approaches that can be utilized in different environments. Localization can be observed in the SCA's system of adapted and localized robotics competitions and contests, as these consider the Sakha Republic's specifications, culture, needs, and potential. They are adapted to the constraints and possibilities of remote schools in the Sakha Republic, as they are based on culture and traditional games. These competitions have helped to stimulate and increase the interest and motivation of teachers, students, parents, and school administrators. For example, the SCA began to remotely conduct robotics competitions and contests adapted to various issues that the schools were facing: slow Internet, lack of robotics sets, and/or competency. The SCA suggested appropriate robot types and solutions to schools that lacked learning and teaching opportunities, for example, a virtual robot simulator—TRIK Studio—which is free and easy to use. It focuses on students' programming and checks the accuracy of students' developed programs by showing that it is in the virtual simulator of various robots. The SCA also remotely conducted competitions and contests with a virtual robot simulator program since it does not require a powerful computer or a fast Internet speed for sending the developed program through email.

Another important factor for the SCA was building support systems that affected the sustainable development of educational robotics in the Sakha Republic. The SCA developed a system to prepare future teachers (university students), who will lead and teach educational robotics. The SCA has provided university students with opportunities to participate in teaching robotics courses and organizing events. The ability to conduct robotics classes, where they can implement lesson plans, methods, and approaches helped them write their graduation thesis and become computer science and/or robotics teachers. All of these former students participated in the SCA's robotics competitions and contests with their students. For example, a full-time after-school robotics teacher (also a former SCA university student) explained that his experience with the SCA allowed him to gain valuable experience, which he applied in his classes. The students he prepared for regional robotics competitions often placed in the top three, and they consistently earned high scores in national competitions. For some, being involved in the SCA's robotics events helped them to obtain useful skills and experiences for developing and organizing robotic events (e.g., competitions). For instance, a teacher, who had been a university student in the SCA's activities, developed and conducted robotics competitions in his local district. Therefore, the system for preparing future robotics teachers helped to foster experienced professionals. This could lead to a sustainable increase in robotics development and solve the robotics teacher shortage in the Sakha Republic.

Moreover, the SCA developed a partnership between public and private sectors that aimed to support the development of educational robotics in the Sakha Republic. This was based on the APEC Learning Community Builders (ALCoB) model, which involves the cooperation of various stakeholders to achieve a common aim. The SCA demonstrated a model of partnership between international, regional, and local schools and educational institutions, as well as business sectors and the government. These partnerships developed trusting relationships and sponsorships to attain the sustainable development of educational robotics. This was made possible because the head of the SCA utilized each sectors' needs and potential to unite them as in robotics development.

Developing a local community to include robotics educators in the Sakha Republic was another support system that used a WhatsApp group‡. Throughout the years, this WhatsApp group has been a supportive platform for consultations from the SCA and experienced teachers. It serves as an exchange of knowledge on a variety of issues concerning the use of robotics in the classroom. Furthermore, some teachers utilize this online platform to share the latest news on educational robotics and their students' achievements, while the SCA utilizes it to promote their robotics competitions, contests, and other events related to educational robotics. The teacher survey results clarified this by showing that they

‡ WhatsApp is a free messaging service through the internet and forming a group of contacts is easily achieved for instant communication across great distances.

received their information on robotics-related events from the SCA NEFU (50.6%) and the Sakha Republic's Ministry of Education and Science (45%). The main resources were email letters (71.1%) and WhatsApp group messages (45.6%). Thus, it was apparent that local community development aided the decision to implement and diffuse educational robotics to many schools with the support of the SCA and early adopters. Utilizing WhatsApp as a platform for group communication was a beneficial choice, as it is the most convenient and popular online messenger in Russia. It seemed to also be the primary source of communication for teachers in remote areas to receive quick responses and consultation on urgent and crucial questions.

The SCA also developed an international support system through the SCA's head, which involved his ALCoB membership as well as his cooperation with other university professors and robotics companies from other countries. This helped the SCA develop international cooperation and joint projects. The SCA started with a main event, the International Summer School on IT and Robotics, composed of members from ALCoB (primarily), the SCA, two Korean high schools, and some Korean robot companies. The summer school consists of robotics lessons and project activities on various topics related to robotics with business planning components as well. The SCA organized the participation of Sakha students and educators in international activities and competitions, which allowed them to experience a variety of cultural and knowledge exchanges on robotics and other educational technologies. Since the groups are multinational, these cultural exchanges increase the students' motivation to pursue robotics and learn about other languages and cultures. In the interview, the head of the SCA also noted that this international cooperation component increased parents' interest in involving their children in robotics activities.

The essential component for the promotion and sustainable development of educational robotics in the Republic was the strong leadership of the SCA head, who was involved in planning, developing, and conducting all key activities. The SCA's head considered the Sakha Republic's potential and limitations when developing on-site training courses in local areas, including localizing and adapting robotics competitions, teacher training courses, and suggesting the appropriate robot types or solutions, according to the local area's specifications. He also perceived the opportunity for sustainability by developing local professional training programs and involving PreK–12 participants in all nine of the activities listed above. He also utilized his resources and networks to develop a local community, PPP, and international cooperation.

RQ2: What were the difficulties of implementing and diffusing educational robotics in the Sakha Republic?

After finding the SCA's key components that influenced the decision to implement and diffuse educational robotics in the Sakha Republic, this study examined some of the challenges faced in 2011 and 2018. This was necessary not only to find obstacles to successful diffusion but also their causes and what affects change. To discover the difficulties in the implementation and diffusion processes, this study conducted a fishbone analysis by using the results of the literature review, surveys, interviews, and observations.

The study developed a two-fishbone analysis with one concerning the issues from 2011 and the other from 2018. The fishbone analysis of 2011 (see Table 1) shows seven categories of issues: (1) Sakha Republic's lack of government support; (2) school administration's lack of involvement; (3) lack of teaching materials; (4) lack of teacher involvement; (5) lack of PPP support; (6) lack of infrastructure; (7) and environmental issues. The results show that the primary issue in 2011 was a lack of support from both the government and the school administration as well as a lack of teaching materials.

The fishbone analysis of 2018 illustrates that some issues and their sequences changed (see Table 2). In 2018, the primary issue remained a lack of governmental support. However, the second primary issue was the lack of teachers' involvement in educational robotics (e.g., educating and promoting). The third chief concern was a lack of support from the school administration. Since the lack of training materials had been solved, this moved from third to sixth place. Moreover, the lack of PPP moved to fourth in the order of importance, while a lack of infrastructure moved to the fifth place.

The results of both fishbone analyses of 2011 and 2018 illustrate that the issue with the largest number of causes is the lack of teacher involvement (see Table 3).

A detailed analysis of the lack of teachers' involvement in 2011 revealed that the primary sub-issue for this category was the teachers' motivation for beginning to teach robotics, their absence of understanding the need for robotics in education, and a shortage of robotics teachers in general (see Table 4). Tracking the causes revealed that the core cause for the lack of teachers' motivation was the absence of understanding the need for robotics in education from both the government and school administration. This was followed by the absence of a development program for promoting robotics in the Sakha Republic, which meant there was no support for training courses, teaching materials, nor a provision of robotics sets at schools. In this case, governmental approval and involvement in the promotion of educational robotics were crucial. In Russia, schools have the right to decide their direction and vision, but they still need to follow the overall conception and order of the federal and regional governments.

In 2018, the main sub-issue regarding the lack of teachers' involvement was the shortage of robotics teachers, their low competency on advanced robotics, and the lack of teachers' motivation (see Table 4). Contrary to 2011 when it was the only issue regarding understanding the need, in 2018, each sub-issue had different underlying causes. For example, one of the reasons for a shortage of robotics teachers was because the number of students in robotics classes had considerably increased. This issue primarily affected remote schools where the shortage of teachers was not only in robotics but also other subjects. In the interviews, the majority of teachers claimed to be the only teacher in their school that could teach robotics. Additionally, since robotics is an after-school class, they still needed to teach the main subjects underlying robotics (e.g., computer science, mathematics).

Furthermore, fewer teachers travel to rural areas to teach due to low salaries, low working hours, and schools' remoteness in general, as the teachers explained. In the case of teachers' low competency in advanced robotics, and a lack of motivation and participation in robotics training courses, one factor that emerged was how few teachers have adequate time to teach robotics and attend training courses due to the reasons listed above. Another factor, according to the head of the SCA, was a constant increase in the variety of robotics, system updates, levels, and methods for teaching robotics, which required continuous training, but not all teachers had the will, availability, or opportunity to learn. The uncontrollable issues that aggravated the issues from 2011 and 2018 included the remoteness of the schools and inadequate transportation systems. The majority of areas in the Sakha Republic can only be reached by special transportation, and the fares are high. This influenced not only the shortage of teachers but other factors, such as the budget and educational opportunities, which made it less of a priority to receive support.

RQ3: What major lessons could be derived from the diffusion process of educational robotics in the Sakha Republic?

After unveiling the key components and difficulties that affected the implementation and diffusion of educational robotics, it was possible to outline a model of the educational robotics diffusion process in the Sakha Republic (see Figure 1). The model consists of five principles surrounded by ten of SCA's key components, where the principles are linked to each other while considering several or all key components. The first principle is that the SCA enhanced the potential for employing educational robotics by focusing on skills, knowledge, experience, cooperation, and local training. The second principle is that the SCA localized educational robotics activities and suggested appropriate solutions for the Sakha Republic after considering needs, constraints, specifications, culture, and norms. The third principle is that the SCA creates systems for some of its activities, such as systems for local and adapted training courses for teachers, robotics competitions, regional/international cooperation, and the systematized development of adapted and localized teaching materials. The fourth principle is that the SCA strengthened all the above steps by utilizing support, which mainly consisted of PPPs, local communities, and international cooperation. Lastly, the fifth principle remains unknown, but it is considered to be the next enhanced principle that is based on the other four principles (see Figure 1).

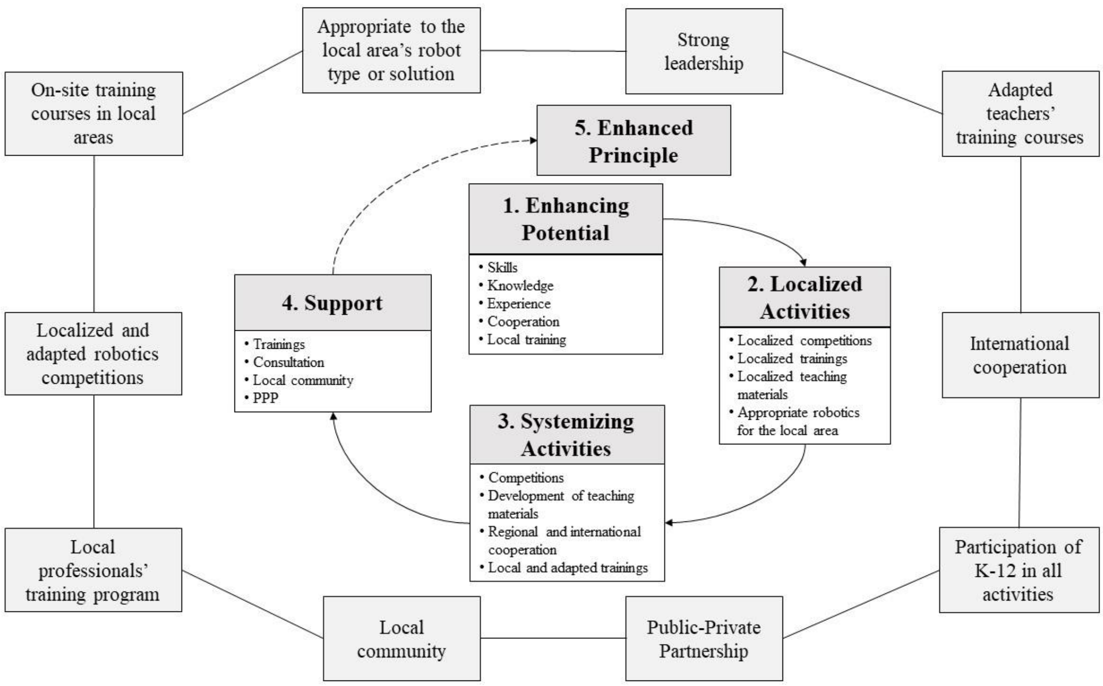

Figure 1. Process model of the SCA's influence on educational robotics diffusion in the Sakha Republic.

The model's major principle was "Support." Figure 2 illustrates the Sakha Republic stakeholders' involvement in educational robotics implementation in 2011. In the figure, as a category moves closer to the dot in the centre, it becomes more involved with the stakeholder and vice versa. Thus, the most involved group in the implementation of educational robotics was the SCA. According to the analysis, it began by conducting educational robotics training courses and events. Supporting the SCA initiative, it expanded the promotion of educational robotics, including the involvement of trained, active teachers. In the interviews, these active teachers stated that they had increased students' motivation to learn robotics primarily by participating in the SCA educational robotics competitions. This also received parental attention, as they began to support the initiative and involve their children in robotics. However, the government, school administration, and other public/private organizations did not understand the need for robotics in education, so they were not yet involved in its implementation.

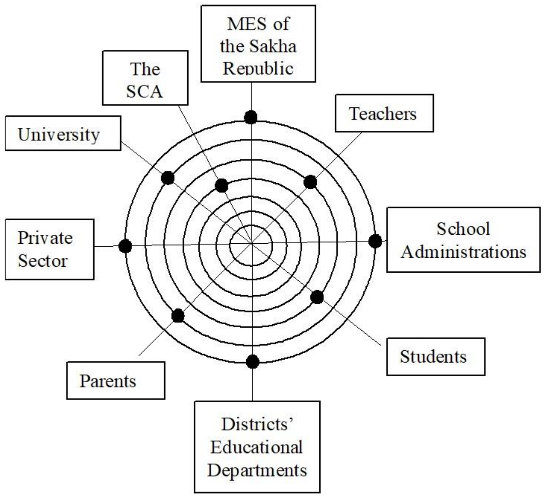

Figure 2. Stakeholders' involvement in educational robotics diffusion in the Sakha Republic in 2011.

The stakeholders' involvement in 2018 was illustrated in Figure 3. After more than seven years, the number of stakeholders that were actively involved in the diffusion of educational robotics grew. This was made possible because the SCA had developed a PPP, which consisted of not only local but regional, national, and international organizations. Moreover, they built a local community of robotics teachers. The partnership between the Russian educational robotics community and the SCA created an opportunity to conduct a variety of robotics competitions, send students to national competitions, and send teachers to training courses. This partnership with international educational institutions, high schools, universities, research institutes, and robotics companies enhanced the possibilities for Sakha students and teachers to not only exchange knowledge and gain new robotic knowledge but also learn about other countries' cultures in the process. The private sector's involvement concerned financing the institution and sponsoring awards at robotics events. The Ministry of Education and Science (MES) of the Sakha Republic also began increasing its involvement in promoting educational robotics by developing training courses; providing robotics sets and training materials; and supporting the SCA's activities and other organizations' initiatives regarding educational robotics.

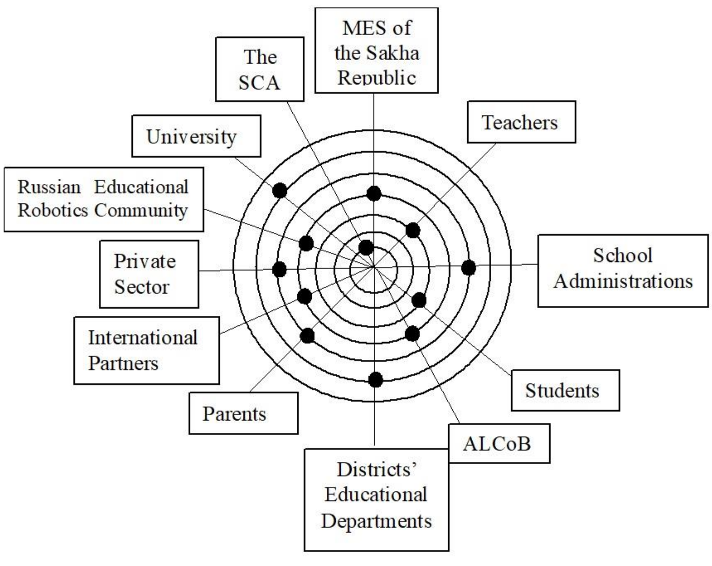

Figure 3. Stakeholders' involvement in educational robotics diffusion in the Sakha Republic in 2018.

Still, not all districts have educational departments that support educational robotics diffusion in their schools. Moreover, the university's involvement has not significantly changed since the beginning. Due to those partnerships, however, the community of robotics teachers were greatly influenced by educational robotics diffusion, although their involvement remained limited. As the focus was primarily concerned with robotics competitions and contests, there is currently a need to strengthen and enhance community involvement.

Discussion

The main goal of the current study was to determine the key components for the successful diffusion of educational robotics in rural regions. The selected case study, the Sakha Republic, demonstrates the potential for implementing educational robotics using a bottom-up approach. The analysis revealed that in the Sakha Republic, the NEFU SCA played a major role in diffusing educational robotics. This study outlined the SCA's activities in a model that consisted of ten components and five principles. Carr (1999), Fagerberg et al. (2006), and Rogers (2010) highlighted, the determinants of diffusion are those that consider people and their communication. Indeed, one of the main determinants in the model was the "support system" that the SCA built. The SCA gathered public and private sectors to build PPP and educators local community showing them mutual benefits, educational robotics advantages, and its possibilities to be used in the Sakha Republic's education. The "support system" consisted of regional government, school administration, university, educators, parents, students, and organizations of not only local but also regional, national, and international levels. The built "support system" helped in developing activities and practices for the diffusion of educational robotics in consideration of local areas' needs, constraints, and possibilities. Thus, their example proofs that for the successful diffusion of technology in education it is important to develop communities and partnerships (Pillay & Hearn, 2009; Rahim & Begum, 2014; Zuckerman, 2020). As Pillay and Hearn (2009) and Rahim and Begum (2014) noted, that when the government, academia, and industry work together, they overcome the issues of rural education and improve its ICT diffusion.

The results of this research also support the idea that there is a need to consider the local context when implementing any technology in the education sector of remote regions (Avery, 2013; Leonard et al., 2016; Pillay & Hearn, 2009; Rodriguez & Najera, 2015). For example, all of SCA's activities are focused on locality. They adapt and localize their training and competitions; conduct on-site training in rural areas, and share the best practices and solutions with teachers from remote regions. The focus on locality means considering not only the local area's needs, constraints, and possibilities but also incorporating the area's culture and norms in the activities (Avery, 2013; Leonard et al., 2016; Pillay & Hearn, 2009; Rodriguez & Najera, 2015). Implementing these practices in the Sakha Republic increased interest from the government administration and parents, which affected the growth of teachers' motivation and student participation.

Most importantly, the findings showed that the diffusion of any educational technology in remote areas would not be possible and sustainable without strong leadership (Ra et al., 2016; Rogers, 2010; Zuckerman, 2020). Ra et al. (2016) highlight that weak or absent leadership leads to an absence of educational planning and a misallocation of resources when implementing educational technology. Rogers (2010) stated that leaders and agents of change play important roles in the diffusion of innovation as they help to adapt individuals' norms and needs. Thus, educational robotics diffusion in the Sakha Republic was possible and sustainable because of the SCA's head, who strategically made plans by using his regional knowledge to ensure that the activities were localized.

Conclusion

The findings of the Sakha Republic' educational robotics diffusion case suggest that for a sustainable and well-organized process, diffusion needs to focus on the specific locality by building a local community and partnership (e.g., PPP) under strong leadership. The local community and/or PPP could also be a massive financial and psychological support for teachers. This process entails not only supporting the diffusion of technology in education but also ensuring that it considers and adapts to local areas' requirements, limitations, and potential. It should be noted that while diffusion is possible through a bottom-up approach, the absence of governmental approval is a challenging constraint; therefore, there is a need to involve governmental support at least during policy development.

The Sakha Republic' case demonstrated that it is possible to implement educational robotics in such an exceptionally remote region, hence, similar and perhaps easier steps can be executed in other rural areas as well. This study hopes to raise awareness about the need to increase research and share cases of educational technology diffusion in rural regions.

Recommendations

Further research on educational robotics innovation diffusion in various rural regions requires more field studies with surveys, interview, and observations to better understand regions' needs, possibilities, and constraints. Particularly, interviewing more robotics' teachers and experts from different regions of the same country or neighbouring countries could show a different perspective or solution for the improvement of educational robotics that can fit the target rural region. Moreover, carrying out a longitude analysis could help to validate the effectiveness of educational robotics programs on students.

Limitations

The limitations of this study were that the survey and interview were only considering those districts and schools that participated during the three events. The study showed that a majority of respondents were from central districts, which are closer to the Sakha Republic region's capital city of Yakutsk. While the respondents of this study also were from different remote north and south districts, there is a possibility of quantitative domination of central regions, who might have fewer issues and challenges. Therefore, there is a need for further study of other regions to validate gained results and to reveal deeper issues on educational robotics diffusion of more remote north and south districts of the Sakha Republic.

This study was also limited to focusing only on the implementation and diffusion process. Thus, such crucial topics, such as program, curriculum development, teaching approaches, and methods of robotics classes, were not analysed. It can be explained by the fact that the main challenge for the majority of schools is in the implementation and diffusion of technology in education. To have a whole picture of educational robotics progress, there would be a need for further research that would cover above-listed topics as well.

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The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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Appendices

Table 1. This fishbone analysis identifies the causes and correlations of issues in 2011 concerning the implementation and diffusion of educational robotics in the Sakha Republic.

	Issues in 2011	Sub-issues in 2011	Number causes (%)	Total (%)	Number of causal and correlation relation (%)	Total (%)
1	Lack of Support from the Sakha Republic Government	1.1. Not understanding the need for robotics in education	13	41.1	0	0
		1.2. Absence of teacher trainings	4.1		0	
		1.3. Absence of teaching materials	6.2		0	
		1.4. Absence of a development program to promote educational robotics	11		0	
		1.5. Absence of robotic competitions	2.7		0	
		1.6. Absence of robotics set provision	4.1		0	
2	Lack of Support from the School Administration	2.1. Absence of a development program for promoting robotics in school	5.5	24	0.7	12
		2.2. Not sending teachers to trainings	3.4		4.2	
		2.3. No incentives provided	2.7		1.4	
		2.4. No hours provided for robotics classes	2.7		1.4	
		2.5. Not understanding the need for robotics in education	4.8		0	
		2.6. Absence of robotics budget	2.7		2.1	
		2.7. No sponsorship for robotic competition trip	2.1		2.1	
3	Lack of Teaching Materials	3.1. Shortage of learning materials	3.4	6.8	4.2	8.5
		3.2. Shortage of teaching materials	3.4		4.2	
4	Lack of Teachers' Involvement	4.1. Lack of teaching materials	0	0	7	71.1
		4.2. Absence of robotics trainings	0		10.6	
		4.3. Absence of motivation	0		13.4	
		4.4 Absence of incentives	0		2.1	
		4.5. Shortage of robotics set	0		6.3	
		4.6. Not understanding the need for robotics in education	0		12	
		4.7. Absence of robotics knowledge	0		6.3	
		4.8. Absence of hours to teach robotics	0		2.1	
		4.9. Shortage of robotics teachers	0		11.3	
5	Lack of Support from Public-Private Partnerships.	5.1. Absence of leadership	4.8	16.4	0	0
		5.2. Research and trainings	4.1		0	
		5.3. Absence of community support	2.1		0	
		5.4. Absence of sponsorship	5.5		0	
6	Lack of Infrastructure	6.1. Software shortage	1.4	4.8	4.2	8.5
		6.2. Shortage of robotics set	2.1		4.2	
		6.3. Slow Internet speed	1.4		0	
7.	Environmental Issues	7.1. Expansive distances	2.7	6.8	0	0
		7.2. Low population	2.1		0	
		7.3. Transportation	2.1		0	

Table 2. This fishbone analysis identifies the causes and correlations of issues in 2018 concerning the implementation and diffusion of educational robotics in the Sakha Republic.

	Issues in 2018	**Sub-issues in 2018**	**Number of Causes (%)**	**Total (%)**	**Number of causal and correlation relation (%)**	**Total (%)**
1	Lack of the Sakha Republic Government's Support	1.1. Weak organization of teacher trainings	4.4		0	
		1.2. Lack of teaching materials	0.9		0	
		1.3. Absence of a development program for educational robotics promotion	13.2	22.8	0	0
		1.4. Weak organization of robotic competitions	1.8		0	
		1.5. No systematic provision of robotic sets	2.6		0	
2	Lack of Teachers' Involvement	2.1. Lack of advanced teaching materials	0		5.3	
		2.2. Lack of teacher participation in robotics trainings	0.9		7.1	
		2.3. Lack of motivation	0.9		8.8	
		2.4. Few receive incentives	0.9	9.6	1.8	
		2.5. Low competency on advanced robotics	2.6		9.7	
		2.6. Inadequate time for teaching robotics	1.8		4.4	
		2.7. Shortage of robotics sets	0		4.4	
		2.8. Shortage of robotics teachers	2.6		15.9	57.5
3	Lack of Support from the School Administration	3.1. Few send teachers to training courses	4.4		8	
		3.2. Limited budget for robotics sets	1.8		4.4	
		3.3. Too few hours for robotics classes	5.3		2.7	
		3.4. Absence of a school development program for robotics promotion	7.9	23.7	0	18.6
		3.5. Lack of sufficient financial contribution	2.6		0	
		3.6. Few sponsor trips to robot competitions	1.8		3.5	
4	Lack of Public-Private Partnership Support	4.1 Insufficient research and training	6.1		2.7	
		4.2. Lack of a knowledge exchange	2.6		8	
		4.3. Lack of promotion	1.8	22.8	3.5	15.9
		4.4. Lack of consultation	2.6		1.8	
		4.5. Lack of community support	5.3		0	
		4.6. Insufficient sponsorship	4.4		0	
5	Lack of Infrastructure	5.1. Slow Internet speed	0.9	2.6	0.9	4.4
		5.2. Lack of robotics sets	1.8		3.5	
6	Lack of Teaching Materials	6.1. Quality of learning materials	1.8	3.5	1.8	3.5
		6.2. Quality of teaching materials	1.8		1.8	
7.	Environmental Issues	7.1. Expansive distances	5.3		0	
		7.2. Low population	3.5	14.9	0	0
		7.3. Transportation	6.1		0	

Table 3. These are the results of the fishbone analysis concerning the issues with the most causes in 2011 and in 2018.

	Issues in 2011	**Number of Causal and Correlation Relation (%)**	**Issues in 2018**	**Number of Causal and Correlation Relation (%)**
1	Lack of the Sakha Republic's Government Support	0	Lack of the Sakha Republic's Government Support	0
2	Lack of the School Administration's Involvement	12	Lack of Teachers' Involvement	57.5
3	Lack of Teaching Materials	8.5	Lack of the School Administration's involvement	18.6
4	Lack of Teachers' Involvement	71.1	Lack of a PPP	15.9
5	Lack of a PPP	0	Lack of Infrastructure	4.4
6	Lack of Infrastructure	8.5	Lack of Teaching Materials	3.5
7.	Environmental Issues	0	Environmental Issues	0

Table 4. These are the top three causes that were mentioned in the detailed analysis of the issue concerning teachers' involvement in 2011 and 2018.

	The Most Mentioned of Causal and Correlation Relation in 2011	**Number (%)**	**The Most Mentioned of Causal and Correlation Relation in 2018**	**Number (%)**
1	Absence of motivation	13.4	Shortage of robotics teachers	15.9
2	Not understanding the need for robotics in education	12	Low competency on advanced robotics	9.7
3	Shortage of robotics teachers	11.3	Lack of motivation	8.8