Classroom Innovation Becoming Sustainable: A Study of Technological Innovation Adoption by Estonian Primary School Teachers

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Abstract. Rapid technological advances provide education systems with a steady stream of novel teaching approaches that are based on various modern technologies. These novel approaches are known as Technology-Enhanced Learning (TEL) innovations, and they are aimed at making learning and teaching more efficient, and providing students with relevant skills and knowledge for the contemporary world. Despite this, TEL innovations often fail to become sustainable in teachers' classroom practices, resulting in wasted human and material resources. Based on existing theoretical frameworks, several TEL innovation process stages as well as the factors that shape innovation acceptance by primary school teachers were outlined. Through interviews with 22 Estonian math teachers, who have already become permanent users of one particular TEL innovation called Robomath, the three stages of innovation acceptance – Awareness, Acceptance and Adoption – are described. In each of these stages, a certain combination of so-called sustainability factors is responsible for leading teachers to the next stage or making them reject the innovation. The role and importance of Contextual, Organizational, Personal, Technological, Social Practice and Perceived Value factors were studied. In order to ensure the sustainability of a TEL innovation, innovation planning should take into account the innovation process stages, ensuring that teachers are adequately supported in each phase, in particular with regard to the factors that are decisive in that particular phase.

Keywords: Technology-Enhanced Learning; Innovation; Innovation Process; Innovation Process Stages; Innovation Process Factors; Sustainability.

1 Introduction

Powerful technological inventions (e.g., the printing press, electricity, television, the internet and personal computers) have always put pressure on the educational systems to embrace the changes. On the one hand, society needs citizens with skills that meet the demands of the new technological reality [1], [2]. On the other hand, the new technological reality allows for the application of more efficient teaching or administration practices, i.e., to apply various educational innovations. In the era of digital technologies, numerous innovations in connecting people and managing knowledge are constantly emerging, and these have the potential to transform education by making it more efficient, accessible and sustainable.

Schools are encouraged to embrace these innovations (including in social networking, cloud computing, artificial intelligence, big data, machine learning, neural networks, robotics and others) through pressure from various education stakeholders (e.g., policy makers, business sector and families) [1]. Several of these innovations target the administrative side of education, e.g., trying to increase the financial efficiency of education. However, a great number of technological innovations in education require the introduction of novel teaching and learning practices, often referred to as Technology Enhanced Learning (TEL). TEL innovations are inevitably aimed at changing teachers' classroom practices, i.e., the processes that involve multiple agents and their interactions within a classroom as a system [3], [4]. This aim at changing classroom practices is met by the teachers' readiness or resistance to accept, adapt and actively implement TEL innovations in their classroom practices [5], leading to the question of TEL innovation sustainability. The concept of sustainability in general refers to the ability to continuously exist. In the context of TEL innovations, ***sustainability*** *is understood as the ability of technology-enhanced pedagogical practices to become persistently integrated in classroom teaching and learning practices* [6], [7], [8], [9]. Initiating TEL innovations that satisfy the sustainability prerequisites will save valuable social, environmental and financial resources while modernizing education and addressing the needs of stakeholders.

However, for various reasons, many TEL innovation projects are abandoned as soon as their funding or external support ends, and instead of becoming sustainable classroom practices, they do not lead to significant changes in educational activities [10], [11]. These reasons can range from political decisions, social needs and insufficient resources for technology, infrastructure and maintenance to the unavailability of learning plans and training courses that could help teachers to connect technology with curriculum needs [10], [12], [13], [14], [15], [16], [17].

Similar problems were previously highlighted by Coburn when she suggested that adoption and implementation of an innovation can be superficial, resulting in the innovation becoming unsustainable, with valuable financial and social resources being wasted [18]. In order to save these resources, the stakeholders in education have started to demand that researchers look for better comprehension of the factors that influence the potential sustainability of innovations.

Several authors have suggested sets of factors that play a role in innovations becoming sustainable and have proposed models of the innovation implementation processes. The aim of this article is to describe the process of an innovation becoming sustainable in a particular context – during the implementation of a new TEL method (Robomath) into the classroom practices by Estonian primary school teachers. We are departing from the existing innovation implementation models by describing innovation stages and the factors that shape this process. In the empirical part of the article, we test both the innovation stages and factors of innovation sustainability proposed by existing models on a sample of Estonian teachers.

2 Innovation Process Stages and Sustainability Factors

2.1 Models and Theoretical Frameworks

The intensity of discussion about the sustainability of innovations has increased in recent decades (see for example [19]). This increased interest towards innovation sustainability (in a wider sense, not simply limited to the sustainability of TEL innovations) has been a motivator for researchers to look for frameworks and to create models that are able to describe its different aspects and stages. In these models, the path that leads an innovation into a persistent and continuous long-term phase is usually described by outlining several stages of an innovation, such as the stages of *becoming aware about the innovation*, *accepting the innovation*, *adopting the innovation* and rarely also as *innovation sustainability*. Also, a set of factors that shapes the innovation processes is presented and analyzed within the context of the innovation implementation models. Subsequently, we will explore some of the leading approaches, describe the innovation process and aim to outline both the stages of this process and the main factors considered essential in ensuring adoption and sustainability of the innovative practices.

The **Diffusion of Innovations Theory** (DOI) by Rogers [20], [21] is one of the earliest theories for explaining how inventions spread in a specific population or social system and is especially useful in understanding trends and consumer behaviors. In addition, Rogers uses adoption predictors that are based on the internal and external characteristics of the adopting organization [22].
DOI has been used in education (e.g., [23], [24]), but some studies suggest that it is not directly usable in explaining the diffusion of complex, standard-based and networked information technologies such as educational innovations in general (e.g., [9], [25]).

The **Technology Acceptance Model** (TAM) by Davis [26] and Davis, Bagozzi & Warshaw [27] is one of the most widely used technology acceptance models, and is based on theories such as the self-efficacy theory [28] and the behavioral decision theory [29] and DOI [20], [21]. In their interpretation of TAM, Gbongli et al. [30] suggest that adoption of an innovation and user engagement are the main indicators of the innovation's sustainability. TAM critics argue that according to the model, once someone has formed an intention to act, their freedom to act has no limits, thus contradicting the limits of the real world. In addition, TAM tends to ignore a user's attitude towards technology [31], the social processes that take place during the development and implementation phases, and the social consequences of the evaluated technology [32]. TAM has been used in an educational context for facilitating the assessment of diverse learning technologies (e.g., see the literature review by Granić & Marangunić [33]).

The **Technology-Organization-Environment framework** (TOE) [34] is an organization-level framework for describing factors that influence and predict technology adoption by focusing on the technological, organizational and environmental contexts [34], [35]. TOE is often described as being markedly similar to DOI [22], [36], [37]. The use of TOE in education is scant, but it is present (e.g., [38]).

The **Unified Theory of Acceptance and Use of Technology** (UTAUT) by Venkatesh, Morris, Davis & Davis [39] is built on eight user acceptance models: the Theory of Reasoned Action [40], TAM [26], the Motivational Model [41], the Theory of Planned Behavior [42], a model combining TAM and the Theory of Planned Behavior [43], the model of PC utilization [44], DOI [20], and the Social Cognitive Theory [45].

UTAUT has been criticized for being unnecessarily complex [32], [46] and for underperforming in real-life settings compared to the performance reported in the originating article [47]. In education, the latest uses of UTAUT include assessing the use of virtual classrooms [48], [49] or social learning [50].

The **Knowledge Appropriation Model** (KAM) by Ley et al. [51] emphasizes the importance of social practices during the different innovation implementation and adoption stages. Innovation-induced changes require organizations and individuals to develop new routines and work procedures that are better able to make use of the innovation. These developments are observable as knowledge appropriation practices and constitute the prerequisites for successful innovation adoption and adaption.

KAM presents three dynamic sets of social practices (Knowledge Maturation, Knowledge Scaffolding, and Knowledge Appropriation) that characterize knowledge management during innovation adoption [52]. Research suggests that different social practices play an important part in transforming knowledge between different levels of organization and beyond [53]. These processes are explained by various social learning and knowledge creation theories (e.g., [54], [55], [56], [57], [58]), but can be observed as a whole, using the KAM model [59].

Although these reviewed models have sometimes been used in the educational context, they were not originally developed for this field. Managing the implementation of new technology in an educational context is described by a few specialized frameworks. The **Concerns-Based Adoption Model** (CBAM) [60] focuses on how different education stakeholders (e.g., teachers, parents, students and policy makers) respond on an individual level to change. CBAM can be used as a tool for designing the strategies for change and facing the possible concerns that stakeholders may have when faced with change [60], [61], [62]. **Technological Pedagogical Content Knowledge** (TPACK) [63], an improvement on Shulman's [64] earlier work, is a framework that seeks to provide teachers with the necessary knowledge for employing effective pedagogical practices in a TEL environment. It considers relevant technological knowledge in addition to content and pedagogical knowledge as a prerequisite for efficient teaching. Still, both of these models do not directly address the issue of sustainability of educational innovations, instead dealing more with change management and teacher training issues.

The previously examined innovation acceptance models differ both in their focus and in the actors that shape the innovation process. TAM is mainly focused on individual users, DOI analyses innovations from the perspective of actors on the individual, organizational and contextual (such as the influence of competitors, policy makers, etc.) levels, and KAM describes the social processes that bind together the actors during innovation maturation. DOI covers a variety of innovation process aspects, but it is often considered insufficient in explaining TEL innovation acceptance and adoption [9], [25]. For example, with a TEL innovation, the initial *decision* in favor of the innovation is often not made by users, thus preceding the *knowledge* and *persuasion* phases. TAM and UTAUT are engaged in innovation acceptance and innovation adoption, and TOE is mostly concerned with innovation adoption.

2.2 Innovation Process Stages

Most of the reviewed models aim at determining the extent of the innovation's adoption after the innovation has been put to use in an organization. In terms of DOI and KAM, an innovation is adopted through a dynamic process that consists of several stages. For example, DOI views this as the innovation-decision process, which comprises the stages of Knowledge, Persuasion, Decision, Implementation and Confirmation. In KAM, three sets of social practices move simultaneously from the stage of experiencing an innovation to the stage of "standardized knowledge, shared understanding and faded support". Stages similar to those in DOI and KAM have been used in education (e.g., [65], [66], [67]) with the aim of determining the moments when an innovation process starts, changes remarkably or ends. In these approaches, three general stages can be distinguished: first – emerging of interest and awareness about the new approach, second – starting to test and experiment with this novel approach, and finally culminates in a situation where the innovation has gradually become a daily part of the teaching and learning process – i.e., the innovation has reached the stage of sustainability. Based on the examination of existing models and putting them into the classroom context, one may conclude that the most commonly accepted TEL Innovation Process (IP) Stages from the teacher perspective would be:

(a) **Awareness** – Teachers have become aware about the innovation and its possibilities, though not utilizing it yet. The sources of this information are training courses, colleagues, the internet, etc.

(b) **Acceptance** – Teachers experiment with the innovation in their teaching practices, often in the context of some collaborative projects. In their trials, they depend on help from other persons. They are not yet convinced whether they will continue using the innovation in the longer term.

(c) **Adoption** – Using the innovation has become a routine part of teachers' everyday teaching practices. Teachers have found the optimal ways and context for using the innovation. Teachers feel confident when using the innovation, and are able and willing to support other teachers if necessary.

From the perspective of sustainability, the Awareness, Acceptance and Adoption Stages can all be viewed as the stages of a sustainability-oriented process. This leads to a situation where some method or procedure becomes an integral part of everyday practices in organizations, and reaches the stage where an innovative approach cannot be considered "an innovation" any more but rather as a routine daily practice. In this sense, adoption is the stage where sustainable use of an innovation has just begun.

2.3 Innovation Sustainability Factors

Comparing and examining the five prevalent models explaining innovation processes reveals six main factor sets that are usually outlined and considered as essential when contributing and shaping the innovation processes: (a) Personal Factors; (b) Technological Factors; (c) Organizational Factors; (d) Social Practices' Factors; (e) Perceived Value Factors; and (f) Contextual Factors. The brief descriptions of these factors are presented in Table 1, together with references to the theoretical frameworks that guide these studies.

Table 1. TEL innovation sustainability factors.

TEL innovation sustainability factors	Description
Personal Factors (e.g., knowledge, skills, experience, openness to change)	Characterize the individuals who accept and adopt the innovations. The personal factors are in a most detailed way described in studies that depart from the DOI and UTAUT models.
Technological Factors (e.g., ease of use of the new technology, its compatibility, trialability)	Characterize the new technology that is being implemented. The technological factors are described in TAM, DOI, UTAUT and TOE.
Organizational Factors (e.g., size of organization, its scope, leadership style)	Characterize the organizations where innovative approaches are implemented. The role of organizational variables is presented in the context of DOI and TOE.
Social Practices (e.g., teamwork, scaffolding, participation of end-users in designing innovations)	Characterize the social practices during creating and implementing the innovation. The social practices that characterize the innovation process are described in KAM.
Perceived Value Factors (e.g., perceived usefulness of innovation, its efficacy, cost-effectiveness)	Characterize how the innovation affects the main processes in the organization (e.g., management, marketing and teaching). The value-related factors are described in DOI, TAM and TOE.
Contextual Factors (e.g., public opinion, political pressure, competitors)	Characterize the wider environment where the implementation of an innovation is taking place. The contextual factors are described in DOI and TOE.

There are already some empirical studies that analyze the innovation process stages from the perspective of innovation sustainability stages and factors (e.g., [8], [68], [69]). Still, most of them focus on either a certain stage or a certain set of factors, and they usually do not look at the innovations in the context of classroom practices.

3 Robomath Innovation Study

3.1 Aim and Research Questions

In departing from the presented three TEL innovation process stages (Awareness, Acceptance and Adoption) and six innovation sustainability factors (Personal Factors, Technological Factors, Organizational Factors, Social Practices' Factors, Perceived Value Factors and Contextual Factors), our aim was to test the stages and role of sustainability factors within the context of one particular TEL innovation, called the Robomath method. We were seeking answers to the following research questions:

RQ1: What are the stages of a TEL innovation implementation process in a classroom context and how long do these stages last?

RQ2: What factors are considered important/influential during each stage of a TEL innovation implementation in the classroom context?

The study was carried out among teachers in Estonia who had started to use a specific innovative TEL approach in teachers' classroom practice, the Robomath method. Robomath is an innovative method used in Estonian basic education schools that employs educational robots in math lessons. The aim of this method is to connect math content via robotics exercises with real-life problems, thus making math more meaningful to students as well as improving student learning engagement and learning outcomes [70]. In addition, the Robomath method is designed to increase student autonomy and self-regulated learning, peer tutoring and collaborative learning (i.e., 21st century skills) with the goal of transforming learning and teaching dynamics in a typical math lesson [71]. For these purposes, students work in small 2-member teams, using one educational robot per team, and they solve robotics exercises that are based on the lesson's math topic. The focus of the robotics exercises[1] is on using the robot as an agent for visualizing math concepts like shapes, time, distance, speed, etc. Programming and robot building only have a secondary importance, although using the Robomath method will result in most students becoming skilled in these areas too.

3.2 Sample and Method

The study sample was based on 189 teachers who had used the Robomath method for more than one school year. Those teachers who believed that the Robomath method had become a sustainable part in their teaching practices were asked to take part in this study. It was explained to them that we were looking to interview them online in order to gather their retrospective evaluation about the process of Robomath becoming a sustainable part of their teaching practices. Twenty-two teachers replied and expressed their wish to share their experiences. Of these teachers, 20 were female teachers and 2 were male teachers. The average experience of teachers with educational robots was 5 years.

[1] Available at: http://bit.ly/2K4t0Ws

The data collection was based on the semi-structured interview method [72]. The interviews were conducted by two researchers using the Zoom videoconferencing software. The interviews took place during the evening hours (18.00-21.00) when teachers were in the safe environment of their homes, thereby reducing their stress levels. The average interview duration was 30-40 minutes, which allowed for the answering of 21 questions (Appendix 1).

At the beginning of the interview, the interviewee was asked about the extent of their experience with educational robots. Then the information about proposed IP Stages was shown to the teacher. The teacher was asked to explain whether their experience confirmed the existence of these stages. For each stage, it was recorded how long it had lasted for the teacher (the stages of Awareness and Acceptance) or how long it has lasted (Adoption Stage). Next, the IS Factors (Table 1) were shown and explained, with examples, to the teacher. The teacher was asked to choose which of these factors made them move onto a specific IP Stage or if they had anything else to add. The teacher was also asked to rank the Innovation Sustainability Factors (IS Factors) in order of importance. The revealed information was recorded into a data table by the interviewer. Before closing the discussion about a given IP Stage, the teacher was asked about the personal motivators that helped them enter the phase under discussion. At the end of the interview, the teacher was asked to describe how they understand the sustained use of educational robots in their lessons and whether they would recommend this method to other teachers.

The interview was piloted with four teachers. The results of the piloting demonstrated that some teachers had difficulties in understanding the meaning of IS Factors. Therefore, we decided that the interviewer would give some real-life examples. In addition, we found it to be more practical for the interviewer to fill in the answers to the questions during the interview by themselves. The pilot also resulted in changing the sequence of questions and adding a few clarifying questions about the sustained use of robots.

The interviews were recorded with the interviewees' consent. The recorded interviews were transcribed. Using the retrospective phenomenological approach [73], the interviews were analyzed in order to answer the research questions. Transcriptions and coding were performed by two researchers.

4 Results

4.1 RQ1: What are the stages of a TEL innovation implementation process in a classroom context and how long do these stages last?

All interviewed 22 teachers agreed that their experience in implementing the innovative TEL method Robomath could be described using the three IP Stages, as described earlier. The stages were:

1. Awareness – lasting up to 6 months, most often up to four weeks.
2. Acceptance – lasting from 1 month to 2 years, most often 7-12 months.

3. Adoption – from 7 months to more than 2 years, most often 1-2 years.

In addition, some teachers suggested "guiding other teachers" as a fourth IP Stage, although most of them revised their suggestion and by the end of an interview considered it as an element of the Adoption Stage.

The duration of the stages, according to the respondents' assessments, is presented in Figure 1. Teachers described the **Awareness Stage** as the time they became familiar with the innovative TEL method. According to teachers, many TEL innovations are based on devices and software that teachers have been exposed to in the past. Yet, this exposure did not communicate clearly enough the benefits of using these devices or software systematically in the classroom, resulting in teachers ignoring it. Many new TEL methods reach Estonian teachers through studies of universities or through state-sponsored training courses, and sometimes through peers, networks, social media and conferences – through various channels of different effectiveness. The Awareness Stage is characterized by the teacher receiving information about the innovative method and its usage scenarios. The teacher becomes aware about the method and its classroom use potential, although not yet using it in their teaching practices. Depending on the person, they have only read about it or tried to independently use it.

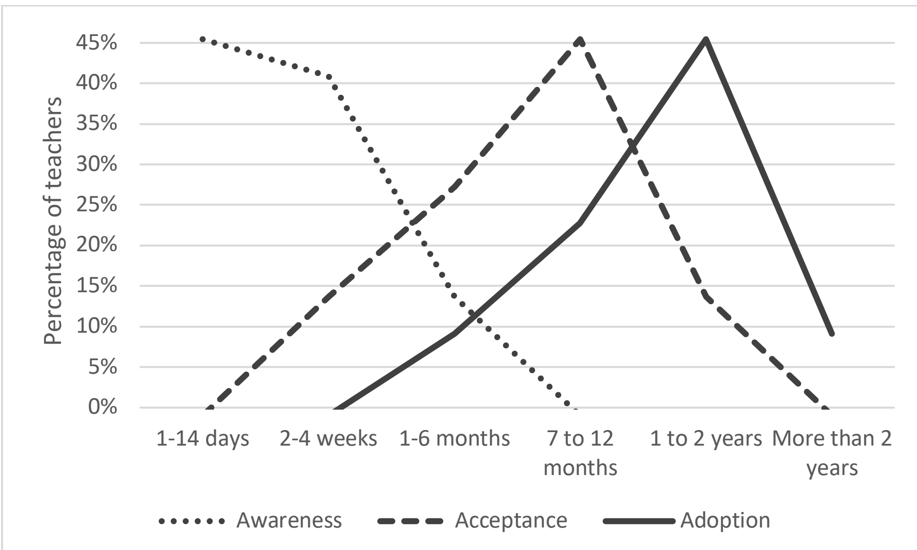

Fig. 1. Duration of the IP Stages.

The duration of the Awareness Stage was surprisingly short. Most of the interviewees considered this stage to last from some days to one month. When asked if the relative shortness of the Awareness Stage was related to the low level of complexity of the examined TEL methods, the teachers reasoned that this was often caused by their chronic lack of time and by their desire to start testing the intriguing innovation in a classroom environment as soon as possible. A teacher recalled, "*We made a decision right away when we agreed to go to the courses. We already knew* *that we were going to work with the Robomath method. We liked this idea and had robots to use*" (T1). However, teachers had time pressure for transitioning from the Awareness to the Acceptance stages, as they had consented to conduct experimental lessons during a certain period. A teacher said, "*I took part in the training and then I tried it a couple of times at home and saw that it wasn't too hard. Then there were a couple lessons to see whether students would accept it, after which I decided to continue with it*" (T2). The Awareness Stage happened to be longer (6 months to 1 year) for those teachers whose schools could not provide the necessary technical resources, who did not teach students in a suitable age group (researchers provided teachers with materials for the 3rd and 6th grades) or who had too heavy workloads.

According to the teachers, the transition from the Awareness Stage to the Acceptance Stage happened when the teacher became convinced about the feasibility of the provided lesson plans and the teaching methods in their classrooms – i.e., they started to use and test Robomath in their lessons to a limited extent. Some of them planned to use Robomath in up to 10-20 lessons without the intention of continuing to use it afterwards. This transition could have been delayed due to the teacher's health reasons or their tight teaching schedule, for example.

The **Acceptance Stage** was described by teachers as a period for trying and experimenting the innovative TEL method in a real classroom setting. Often, such experimentations happen as part of a study, project or collaboration plan. Frequently, such initiatives involve support persons (e.g., educational technologists, another teacher, etc.). In this stage, the teacher is not yet convinced about whether they will continue using the method. Instead, they look at this experimentation as a limited period that needs to be completed due to pressure from the management. According to the teachers, "*Management seemed to favor such innovative methods*" (T3), and "*We agreed on common rules and I didn't want to be left behind, not that I wouldn't want to do it*" (T4). Due to the experimentation being time consuming, teachers seek excuses such as "*lack of time*", "*too complex*" and "*outside the curriculum scope*" in order to leave the project. To prevent such situations, some schools award their teachers for conducting these experiments. The Acceptance Stage usually ends when a teacher has conducted a previously agreed number of lessons or when a school-year or half-term ends. Next, the teacher summarizes their experience for themselves and for management and proposes either to continue experimenting with the innovation for one more year, including it into school's curriculum, or rejecting it due to its excessive complexity or due to a lack of time or other resources. Rejection does not indicate moving back to the Awareness Stage; rather, it leads the innovation to become abandoned.

Most of the teachers claimed that the Acceptance Stage lasted for about one school year. During this stage, they were often assisted by their school's educational technologist or another teacher, who helped to prepare devices, conduct robotics experiments and solve technical problems. This made it possible for the teacher to focus on communicating the theoretical part and explaining connections between robotics content and math to students. "*The whole school year was spent on trying out learning plans and it was still just experimentation*" (T5).

The teachers mentioned the time-consuming nature of preparing lessons and creating new lesson plans, the slower learning process compared to traditional methods and the difficulties in complying with curriculum as major obstacles for transitioning from the Acceptance Stage to the Adoption Stage. Primary education teachers indicated that they used lesson time from other disciplines such as arts and language for conducting the Robomath lessons. According to one teacher, "*I am using it in integrated lessons of art and technology. It is because in math lessons I feel I am just not able to do it. I am responsible for reaching a certain level so that these students could pass the tests, the national standard-determining tests*" (T6). The transition could have also been lengthened by the insufficient organizational ability of conducting technology-enhanced lessons. A teacher said: "*We understood that moving robots from one classroom to another is not justified and that we would need a dedicated robotics class. We built the first robotics class, and we had to buy more equipment as we didn't have enough. It was a big investment*" (T4).

The transition from the Acceptance Stage to the Adoption Stage happened when teachers became convinced about Robomath's beneficial influence on student learning motivation and engagement in lessons as well as on learning outcomes. Several teachers in particular highlighted a question their students often asked: "*Will we also have a robot-supported lesson this week?*" and emphasized how robot-supported lessons filled their students with positive energy. "*It is interesting for the children; it develops technical apprehension and it makes lessons exciting*" (T7). As additional criteria for this transition, teachers mentioned their sufficient confidence when programming robots and becoming independent of the provided lesson plans, while acquiring the skills for creating customized materials for their own lessons.

According to the teachers, the **Adoption Stage** is a phase where use of the innovative TEL method has become a part of the teacher's everyday teaching practices. They have found an optimal frequency for its use (throughout the school year, limited to certain topics, etc.) and students with whom to use this method. The teacher is confident when using the method and is able to support other teachers. In the Adoption Stage, teachers became more confident about their skills and started to create their own lesson plans or to choose topics for which Robomath method could be used. In addition, they became able to conduct their lessons without the help from support persons, although many teachers still preferred co-teaching, as it was simpler. Many teachers endeavored to conduct at least one method-based lesson each half term or up to 10 lessons during a school year.

A typical teacher in the Adoption Stage is active as a promoter of the innovation in their school and guides new teachers to start using it. Teachers that are more energetic also promote the innovation outside their schools, either conducting introductory workshops in education conferences or writing articles for professional journals. Many Adoption Stage teachers do not measure how many lessons they have conducted this way. Instead, they are looking for ways to expand the innovation into other disciplines or activities, e.g., to art lessons. These teachers have also understood the limitations of the innovations – disciplines that are unsuited to the method or where its efficiency would be too low. Adoption Stage teachers have typically recruited followers from other teachers of their school, and their cooperation with educational technologists is based on the goal to provide students with a more personal approach. A teacher said, "*I develop some working lessons with robots, just about enough. And I know what certainly works well. But when I try something new and see that it doesn't work, I know that next year I will not use it*" (T8).

Our results suggest that the IP Stages approach can be used for describing the development trajectory of TEL innovations in a classroom context, starting from being introduced to the innovation to sustainably accommodating the innovation into their teaching practices. Based on the example of implementing the Robomath method in Estonian schools, we recorded the duration of the Awareness Stage as 6-12 months and the duration of the Acceptance Stage as 1-2 years.

4.2 RQ2: What factors are considered important/influential during each stage of TEL innovation implementation in the classroom context?

We also asked teachers to indicate for each IP Stage they considered the IS Factors as being important in supporting continuous usage of the Robomath method. For this, we introduced the IS Factors to interviewees and asked them to indicate the three most influential IS Factors for each IP Stage. Next, we counted how many times an IS Factor was indicated as one of the three most important factors in a certain IP Stage (Table 2).

Table 2. The factors considered important during each IP Stage (number of teachers who placed this factor among their top three).

IP Stage	Awareness	Acceptance	Adoption
Contextual Factors	0	4	6
Social Practices' Factors	8	13	7
Perceived Value Factors	5	11	11
Organizational Factors	14	12	14
Personal Factors	19	11	9
Technological Factors	14	14	11

It turns out that various sets of IS Factors play a role during the different IP Stages of the innovation process. Some IS Factors (e.g., Organizational Factors) had relatively similar importance during all stages, while the role of others either increased (e.g., Perceived Value and Contextual Factors) or decreased (e.g., Personal Factors) over time.

In the **Awareness Stage**, the most crucial IS Factors were Personal Factors (indicated by 19 teachers), followed by Organizational Factors (n=14) and Technological Factors (n=14). According to one teacher, "*Of course, at first it was my personal interest. I had conducted a robotics club for several years and felt that it was not enough*." (T9).

During the **Acceptance Stage**, all IS Factors, with the exception of Contextual Factors (n=4), had almost equal importance (n={11,11,12,13,14}, Table 2). One teacher noted, "*We had a community of robotics. There was a consistent sharing of experiences so that teachers could be as confident as possible to continue with the next topic*" (T4). Another teacher recalled, "*We wanted to introduce something into the educational process that was more modern and interesting for the children. We received either confirmation or a suggestion that it could positively affect the interest children have in mathematics and the effectiveness of teaching mathematics, so we decided to try it*" (T10).

In the **Adoption Stage**, the most decisive IS Factors were Organizational Factors (n=14), Technological Factors (n=11) and Perceived Value Factors (n=11). According to one teacher: "*The organizational factor comes first due to the fact that the method is on the schedule. We already have a fairly large group of teachers at school who are involved in this process and who appreciate the Robomath innovation*" (T1). These results suggests that the success of the Adoption Stage depends on the innovation's beneficial influence on students, on teachers' sufficient confidence, and by the existence of resources.

At the same time, Contextual Factors seem to play a minor role in shaping the success of the whole innovation acceptance process.

Figure 2 describes the relative importance of the factors during each of the three stages, presenting only the factors that were mentioned by more than half of our respondents.

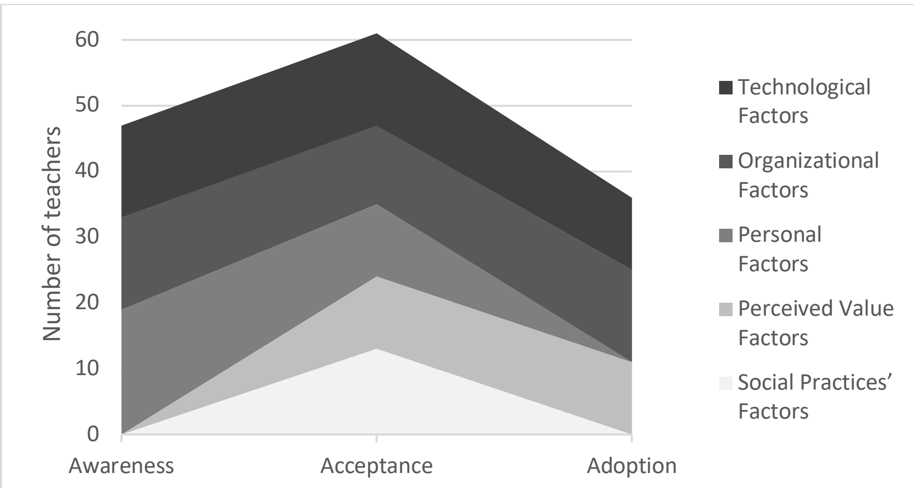

Fig. 2. Top IS Factors in each IP Stage, indicated by at least half of the teachers.

In conclusion, two sets of factors – Technological Factors and Organizational Factors – are almost equal in their impact on the innovation process throughout all its stages. However, in the Adoption Stage, the influence of Technological Factors becomes lower while that of Organizational Factors is greater. The importance of Personal Factors is the highest in the Awareness Stage, declines remarkably in the Acceptance Stage and becomes inconclusive in the Adoption Stage. Social Practices have their highest impact in the Acceptance Stage, as teachers are using informal learning in a social environment for actively constructing their understanding about the innovation's strengths and weaknesses, in order to decide whether to accept or reject the innovation. The role of Perceived Value Factors becomes apparent in the Acceptance Stage and becomes even more important in the Adoption Stage. This trend correlates to that suggested in DOI – users may reject the innovation as soon as they are not able to perceive the benefits of using the innovation vs alternative methods. In the context of education, the perceived value of an innovation is reflected in its positive influence on the teaching and learning processes. We conclude that ignoring even some of the IS Factors (with the exception of Contextual Factors) may increase the possibility of the innovation failing.

5 Conclusions and Discussion

Rapid technological advances lead educational systems and their stakeholders to initiate various technology-centered innovations with the aim of enhancing teaching and learning practices with technology, i.e., of introducing Technology Enhanced Learning. Research indicates that many of these TEL innovations fail to become sustainable (i.e., they change neither teachers' teaching practices nor students' learning practices). An unsustainable innovation, however, often means that invested valuable human and material resources become wasted. The aim of this paper is to contribute to the body of knowledge that helps researchers, policy makers, administrators, teachers and students to design and implement TEL innovations that have a greater potential to achieve sustainability. For these purposes, we strived to identify the factors that influence TEL innovation sustainability (IS Factors), and to determine their relevance in different TEL innovation process stages (IP Stages). The obtained information allowed us to develop the conclusions and suggestions presented as follows.

First, the study confirmed our assumption that a TEL innovation process can be described as a multi-stage process, namely: (a) **Awareness** – through training courses, their peers or media a teacher has become aware about the innovation and its possibilities, although is not yet using it in their classroom; (b) **Acceptance** – a teacher is experimenting with the innovation in their classroom and is building an understanding about its suitability for their needs, but has not yet decided if they will continue using it in the longer term; and (c) **Adoption** – the innovation has become a routine part of the teacher's everyday teaching practices, i.e. is sustained. As the teacher finds the innovation suitable for their purposes, she or he is able to assess when to implement it and when not, and is able to advise other teachers when needed. Similar three-stage developmental process for educational innovations (survival, mastery of technology, using technology to impact classroom practices) have already been offered by Fuller [74], Loucks & Hall [65] and Sandholtz, Ringstaff & Dwyer [75], but the focus of these works is on teachers' technology acceptance, not on an innovation's sustainability – thus they do not describe what extrapersonal factors (and how) influence the progression of an innovation process from one stage to another. Owston (2007) points out that these three stages are similar to experiences that any teacher has at the beginning of their careers. There are also similarities to the innovation-decision process stages offered by Rogers [20], [21] that outline the stages of Knowledge, Persuasion, Decision and Implementation. We suggest that in an educational context the stages of Persuasion and Decision can be merged into the Acceptance Stage. Deaney & Hennessy [68] and Owston [8] suggest the presence of pedagogical factors, which in our context can be viewed as a part of Perceived Value Factors. In addition, the Social Practices' Factors that describe the social practices of an innovation process (e.g., participation of end users), which in our empirical study were especially important in the Acceptance Stage when teachers shaped their decision to continue using the innovation, were usually overlooked in the papers on TEL innovations. Using an innovative method does not indicate a method's sustainability, as this is observable already in the Acceptance Stage where the user has not decided on future use. The KAM model is one of the tools that helps, by observing users' behavior patterns over time, in more correctly estimating the current IP Stage and thus the potential for sustainability (e.g., according to Rodriquez-Triana et al. [76], these different practices are related to the increased classroom implementation of innovative methods among teachers).

Second, IP Stages have different durations. In our case, the Awareness Stage generally lasts less than one month, as teachers tend to rapidly decide for or against an innovation due to their chronic lack of time. However, after their initial approval, teachers will just start shaping their understanding about the feasibility of the innovation. This stage of Acceptance may last as little as a month, but most commonly, it will last for 7-12 months. Although the Adoption Stage commences right after the Acceptance Stage ends, it takes time for a teacher to become aware that the innovation has become firmly rooted in their teaching practices. In our study, teachers came to this understanding within two years of being introduced to the innovation. Similarly, Owston [8] suggested that a TEL innovation could be considered as sustainable after having been carried out for more than 2 years without additional financial resources. However, Niederhauser et al. [77] indicate that after "*initial participation and acceptance*" in some cases, it is difficult to identify "*when and how technologies were adopted and implemented*".

Third, at various innovation stages different IS Factors contribute to the success of an innovation. The importance of Personal Factors fades throughout the innovation process, and it has the most crucial impact in the Awareness Stage at the beginning of the innovation process, when it shapes the decision of teachers on whether the innovation would be "**nice to have**" for them. The importance of Perceived Value Factors, on the contrary, grows throughout the innovation process, and it shapes the decision of teachers on whether the innovation is a "**must have**" for them. With the exception of Contextual Factors, all other IS Factors are responsible for making the transition from "nice to have" to "must have" as smooth as possible for teachers. However, although only 27% of teachers indicated that Contextual Factors are active in Adoption stage, the importance of these factors was steadily growing – suggesting that in a longer period, these factors could become more important for the innovation's sustainability. In addition, the low reference rate may also indicate that for most of the teachers, the support from their schools was seamless and there were no problems. The importance of Technological Factors and Organizational Factors in all IP Stages suggests that teachers need to be technically supported in all of these stages, and that they expect material and immaterial help from their organizations. In addition, teachers need social scaffolding in the forms of a dedicated community, co-creating an innovation-related artefact and discussing ideas (see also [52]) in the Acceptance Stage, as these social practices may help them to become convinced about the innovation's wider usefulness and its acceptance by a wider community of professionals.

Sustained use, if achieved, is not a perpetual motion. The organization needs to continuously support the use of the innovative method (e.g., renewing software license subscriptions, obtaining spare parts for devices, providing training courses, support personnel and adapted classrooms, and taking care of other Organizational Factors). In addition, teachers need to continuously gather evidence about the method's positive results (Perceived Value Factors) in order to maintain their personal motivation. Likewise, many authors (e.g., [8], [68], [77]) indicate that the innovation's sustainability depends on several personal and extrapersonal factors.

Based on these conclusions we would suggest that TEL innovation initiatives should take into consideration the fact that this is a multi-stage process. In effect, this means that different support activities and resources should be planned for each IP Stage, which ensures transitioning to the next stage and providing an opportunity for the innovation to become sustained. A TEL innovation process should be designed for a longer time, up to several years, in order to provide participating teachers with the required support. We advocate that for a TEL innovation to become sustainable, its promoters should allocate most of the support resources to the Acceptance Stage, i.e., to the period of 7-12 months from the introduction of the innovation. In the Adoption Stage, it is possible to fade this support as teachers have already made their decisions and gathered a critical amount of knowledge to independently continue using the innovation. For example, in the Awareness Stage it is most important, in a relatively short time, to convince teachers that they would be able to use the innovation-related technology in their classrooms. In subsequent months (up to 12 months from the introduction of the innovation), i.e., in the Acceptance Stage, the professional management of the innovation process has most relevance on the later sustainability of the innovation. The innovation process needs to seamlessly support teachers' social practices by providing teachers with what they need during this time: e.g., resources and support to adapt lesson plans to their classroom specifics and information to help them perceive the educational value of the innovation. In the Adoption Stage, the innovation becomes sustained in teachers' teaching practices and the teachers' need for technical support fades.

These requirements can also be viewed from another angle – namely, how to arrange the innovation process in a situation that involves time pressure. There may be situations with a seeming urgency to apply some innovative methods (for example, Emergency Remote Teaching during the COVID-19 crisis). Despite the urgency of these situations, the planners need to understand that all innovation process stages need to be passed, and take into account all IS Factors. In addition, planners should realize that reaching the Acceptance Stage is not an indication of teachers deeming an innovation to be a "must have" for them. In the Acceptance Stage, teachers are insecure and vulnerable, and they need sufficient support to validate (through social practices, through their own experience) the appropriateness of the innovation for long term use.

The empirical study is based on an innovative TEL method called Robomath. This means that we used a relatively specific kind of classroom innovation – educational robots in basic education math lessons – as the study's focus. Compared to other TEL innovations, Robomath can be considered quite attractive, though it is also complex and requires an input of time and effort.

Further research should prove how generally applicable our results are, through research into using other kinds of TEL innovations in different settings, not only a classroom context. Besides examining other technologies, a more varied sample should be used in order to get better understanding about innovation's sustainability characteristics. For example, the teachers who have rejected an innovation should be interviewed. In addition, a longitudinal study with the focus on an innovation's long term social acceptability is required, considering that a social change needs more time than any technological change.

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Appendix 1

Interview plan with Robomath teachers

Introduction
Thank you for taking the opportunity to participate in this interview. The results of the interview will be used for a research article that, based on the assessment of teachers using Robomath, will also try to find out if there are different factors in the introduction of a new technology-enhanced learning method and whether these factors vary at different times.
The interview lasts about 30 minutes, and during it I will show you a few texts on the screen to help answer the question better. Answers are used anonymously only. I also ask you for permission to record this interview for research purposes only.

1. *I will start recording and we will start. If you think back now, how long ago and how did you first encounter robots?*
2. *When you think in the context of Robomath, when did you first come across it?*
3. *Now is the right time to discuss together that when something new is introduced, there are different stages. When you started to use Robomath, what stages did you pass?*
4. *Do you think these can be divided into three stages: Awareness, Acceptance and Adoption? I will show these steps on the screen. Did you encounter the same stages or were there more or less of them?*
   The interviewer shows a document with three steps to the screen in Zoom.
5. *Let us start with the first stage – Awareness. How long did it take?*
6. *Let us try to think about what was important for that, or what determined that you started getting to know it at all? I will share on the screen 6 factors suggested by the scientific literature. Look at them calmly, and tell which of them influenced you all - not all of them may have been active and in what order of importance would you put them?* The interviewer shares a document with six factors on the screen in Zoom.
7. *What was the biggest motivator for you to become interested in Robomath at all?*
8. *During the Awareness phase, did you happen to share with others? I will share a table on the screen again, and here is the same story: look, and mention, what activities did you do? There is no need to prioritize them here.* The interviewer distributes a document in the Zoom, showing social practices.
9. *Let us move on to classroom testing (Acceptance Stage). How long did this period take, and what did you do there?*
10. *Let us go together now and look at the factors that were important to you at this stage, when you started experimenting with Robomath, and we will put them in order of importance as well.* The interviewer shares a document with 6 factors on the screen in Zoom.
11. *What motivated you the most during the Acceptance stage?*

12. *How did you share Robomath with other people?* The interviewer distributes a document about social practices on the screen in Zoom.
13. *How long do you think you have been in Adoption stage? How long you estimate each stage has last*
14. *What were the most important factors for you to permanently integrate Robomath to your lessons? I will show the factors on the screen*. The interviewer shares a document with six factors on the screen in Zoom.
15. *What is the biggest motivator for you in permanent use?*
16. *If you think of yourself as a regular user, how do you communicate with others on this topic?* The interviewer shares a document on screen in Zoom.
17. *For you, does Adoption only mean that you personally use or engage with a larger community or promote it somewhere, and have you brought, helped or encouraged someone into that community? Do you have any more volatile plans for the future in the use of robots in teaching?*
18. *What does your regular use look like? Is the use uniform across the school year or are there periods of more intensive use?*
19. *Do you recommend the use of robots in teaching to others? If so, then why – and if not, then why?*
20. *Distance learning - what were the solutions?*
21. *Is there anything you would like to add that was very important but was not addressed in our previous talk and that supports Robomath's sustainable use?*