Chapter 7
Understanding Non-functional Requirements for Precollege Engineering Technologies

Mario Riojas, Susan Lysecky, and Jerzy W. Rozenblit

Abstract. The design of accessible learning technologies for precollege engineering education is a multi-faceted problem that must take into account a multitude of physical, social, and environmental factors. Using literature reviews and assessment by a participant observer during an 18-hour intervention with a local middle school, we propose that the elicitation of non-functional requirements for precollege learning technologies can be better understood by dividing schools in clusters which share similar resources and constraints. Developers can utilize the proposed scheme as a means to establish minimal criteria that learning technologies must satisfice to be viable for adoption by a wider range of users and better meet the needs and priorities of students and educators.

7.1 Introduction

Precollege engineering education is a constructive discipline requiring both conceptual and procedural proficiency. The development of conceptual knowledge allows an individual to think about constructs in concrete and abstract ways. For example, considering the personal computer, abstract conceptual knowledge may relate to a system that processes and displays information, while concrete conceptual knowledge relates to the computers components, the function of the individual components, and the relationships among components. Moreover, a generalized understanding of systems independent of domain-specific knowledge (e.g. personal computer) demonstrates a deeper conceptual understanding. An analogous distinction exists between individuals with low and high levels of procedural knowledge. Individuals with a low level of procedural knowledge act randomly or based on

---

Mario Riojas · Susan Lysecky · Jerzy W. Rozenblit
The University of Arizona, USA
e-mail: `mriojas@email.arizona.edu`,
`{slysecky,jr}@ece.arizona.edu`

R. Klempous and J. Nikodem (eds.), *Innovative Technologies in Management and Science*,
Topics in Intelligent Engineering and Informatics 10, DOI: 10.1007/978-3-319-12652-4_7

intuition, while high-level performers accomplish complex tasks with significant understanding of the separate decisions and steps taken to achieve their goals (Star 2000). With regard to engineering education, to produce effective solutions, learners must not only understand the underlying principles and theories (i.e., conceptual knowledge), but must also have the dexterity to nurture these solutions from a mental construct to a physical or virtual implementation procedural knowledge.

An elementary definition of engineering practice includes systematic approaches to problem-solving, specialized knowledge (e.g. design principles, systems theory, math- and science-based knowledge), and the ability to integrate and develop technology-based products and solutions (Sheppard et al. 2006). As a result, learning technologies in engineering education serve not only to assist curriculum and instruction in conveying conceptual understanding, they are also essential to developing procedural knowledge. The value of engineering education at the precollege level has been acknowledged by the National Academy of Engineering (Katehi et al. 2009) and recently by the National Research Council as part of its framework for precollege science standards (NRC 2011). However, it remains unclear how prepared the average school is for meeting the challenges of teaching engineering concepts and practices. While learning technologies abound providing alternatives ranging from open-source modeling software and open-hardware microcontroller kits to off-the-shelf robots and sophisticated computer-enhanced construction kits we argue that because many of these resources are not sensitive to quality requirements and constraints they are not as ubiquitous as they could be (Riojas et al. 2012). Especially at the middle-school level (grades 6th to 8th), where out-of-field teachers are often responsible for courses they lack background in (Peske and Haycock 2006), access to adequate curriculum and learning technologies is problematic. Moreover, dedicated engineering laboratories are uncommon at the middle-school level (Foster 2005).

Functional requirements refer to the functionality and behavior of a system, that is, actions a system is expected to perform given an input or stimuli. Performance requirements are described by the products time and space boundaries. Functional requirements and performance requirements typically serve as measures for technical excellence. In contrast, non-functional requirements capture quality characteristics such as usability, portability, or maintainability. The proper elicitation of requirements affects the quality of use as well as how successfully a product will satisfy user needs (Fig.7.1) (Glinz 2007). Bevan (1995) defines quality as the extent to which a product satisfies stated and implied needs when used under stated conditions. While technical functionality will always be a priority in learning technologies, it is equally important to emphasize quality-in-use and the satisfaction of user needs across a variety of work environments. Products that are considered examples of high technical excellence are not necessarily used at high rates. Adoption of quality-in-use measures within the domain of educational technologies will likely increase the satisfaction level of users (Bevan 1999).

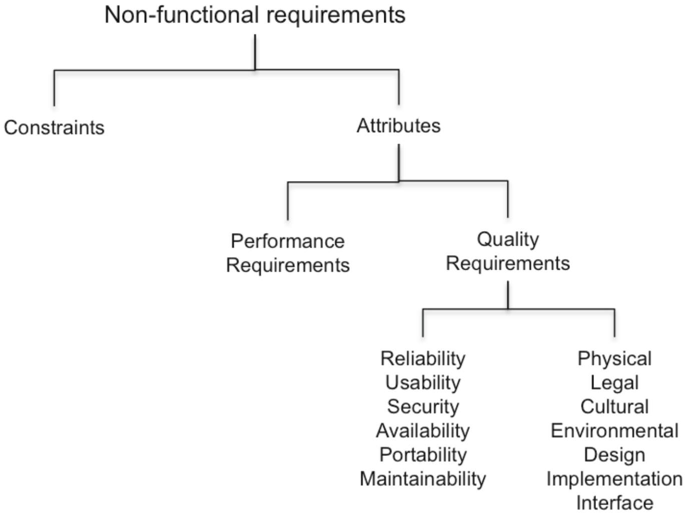


Fig. 7.1 Example of non-functional requirements

Incorporating non-functional requirements at an early stage of development would enable designers of learning technologies to achieve satisficing solutions for representative precollege school clusters, following the description in Lu (2009), of the balance between collective rationality and optimality in a complex system. In socio-technical problems, global optimality does not necessarily entail finding an unequivocal best choice for each stakeholder in the universe of possible solutions. Rather, approximations of a solution are provided to which heuristics can be applied to identify satisficing solutions. Because engineers are typically working with partial information and uncertainties in socio-technical problems, a way to achieve global optimality could be finding the best alternative from a set of solutions that satisfice a fundamental collection of requirements stated by stakeholders in the most rational manner.

A collective rationality that elucidates the needs and constraints that rule representative school clusters must be established to enable the development of technologies. Such technologies should have greater odds of meeting the challenges that many schools confront regarding environmental limitations to precollege engineering instruction. In this work, we present insights into the elicitation of non-functional requirements and the identification of constraints relevant for the design of learning technologies that can achieve greater ubiquity as well as improvement in the quality of user experience.

7.2 Problem Statement

In the realm of precollege engineering instruction, there is a need and opportunity to expand the definition of learning technologies beyond Information and Communication Technologies (ICT). The customary definition of ICT in education refers to products that allow the user to manage information electronically in a digital form; for example, personal computers, Internet access, handset devices, microcontrollers and robot kits. However, learning technologies need not be limited to these devices, rather many alternative platform possibilities are useful within engineering education.

Engineering concepts and practices can also be cultivated with non-digital technology. This approach can be illustrated by looking at the engineering work created during the Renaissance period (Ferguson et al. 1994) and more recently, through engineering projects presented by Sadler and collaborators (Sadler et al. 2000), which demonstrate the feasibility of teaching engineering concepts with non-digital technology. To the best of our knowledge there is no research work which suggests that ICT products are a necessity to ensure high quality precollege engineering education.

The integration of ICT into secondary schools is a complex task. At one time, it was believed that it could be solved through policies which stipulate, for instance, the number of computer labs and laptop carts with Internet access in schools. However, this strategy failed to reach many of the objectives that policy makers and educators expected. Often, schools have computer labs but problems such as limited access, maintenance, and lack for training for teachers prevent full utilization of these facilities (Cuban et al. 2001; Margolis et al. 2008).

Moreover, many countries are economically disadvantaged in terms of the acquisition of technologies. For example, Grace and Kenny (2003) state that if all of Zimbabwes discretionary spending at the secondary level was used to provide students with computer access; this will buy 113 hours a year per student in front of the computer. The remaining (approximately) 1240 hours per year would go unfunded. In many of these areas, changes that would enable access to ICTs are considered an unrealizable short-term goal. Rather, expanding the concept of learning technologies for precollege engineering education to include non-traditional learning technologies would be particularly beneficial for such countries.

Many researchers have underscored the need to define the characteristics for successful learning technology planning and recognize requirements engineers as key stakeholders in the integration of technologies into secondary schools (Fishman et al. 2004). As advocates of precollege engineering we must remain cognizant of challenges faced by teachers and students when utilizing learning technologies. In general, we perceive a loose relationship between the designers of technologies and the actual conditions under which teaching and learning take place in precollege settings. Consequently, the available technologies for engineering education are unable to accommodate the needs of average teachers and students especially in resource-constrained schools where access to ICTs is limited (Perraton and Creed 2002). In order to reduce this disconnect, design guidelines are needed to enhance the usability and ubiquity of learning technologies. Our work pursues the following objectives:

1. Illustrate quality requirements and constraints for the development and adaptation of learning technologies for precollege engineering instruction.
2. Establish a shared understanding regarding needs and effective practices for the design and development of learning technologies for precollege engineering instruction.
3. Develop a set of measures assessing engineering learning technologies respective to the schools where they are meant to employ.

To reach the aforementioned objectives, a goal-oriented engineering approach is proposed where the expectations for a product are defined as abstract goals and then refined into functional requirements, performance requirements, specific quality requirements and constraints (van Lamsweerde 2001).

Functional and performance requirements are fundamental to reach usability expectations and quality-in-use standards but they are specific to the system-to-be. Therefore, an attempt to render representations of these requirements to be used as general tenets by developers of learning technologies is impractical. However, we can suggest methods to identify quality requirements and constraints if we take into account the different types of schools that teaching and learning occur in, for example, schools with and without technology oriented classrooms i.e., classrooms with four or fewer computers (Margolis et al. 2008). Each category (or school cluster) is governed by similar physical and social constraints. Understanding these constraints is paramount for developers of new technologies and for individuals interested in adapting existing technologies to be employed in typical precollege classrooms.

The elicitation of requirements was performed through literature analysis and participant observation. Our literature analysis focused primarily on ICT. However, because technologies for engineering education are not restricted to ICT, participant observation was carried out to capture additional challenges that could not be inferred from the literature analysis. Our main purpose is to illustrate the usability issues related to technology-supported engineering learning at the precollege level.

7.3 Literature Analysis

To identify non-functional requirements we examined literature about challenges in using learning technologies in schools. The spate of published works on the topic is an indicator of its ongoing relevance. The majority of the papers did not consider engineering education specifically, but analyzed the integration of learning technologies in a broad manner from the perspective of teachers, students, and school systems. A majority of the publications focused on a narrow definition of ICT. Nevertheless, we consider relevant the findings on quality requirements and constraints presented in previous works because our experiences working with other types of

Table 7.1 Most frequently identified obstacles impeding the integration of technologies into schools

Identified Obstacles	Description	No. Refs	References
Technical Support	A reliable service which provides regular maintenance and repairs equipment on time	11	Beggs 2000; Blumenfeld et al. 2000; Cuban et al. 2001; Earle 2002; Fishman et al. 2004; Hew and Brush 2007; Groves and Zemel 2000; Kay et al. 2009; Keengwe and Onchwari 2008; Rogers 2000; Wilson et al. 2000
Availability and Accessibility	The presence of equipment in schools and the facility to use them with minimal restrictions	10	Beggs 2000; Blumenfeld et al. 2000; Cuban et al. 2001; Earle 2002; Fishman et al. 2004; Hew and Brush 2007; Groves and Zemel 2000; Hohlfeld et al. 2008; Kay et al. 2009; Rogers 2000
Teacher Training	Opportunities to receive instruction on how to use technology for pedagogical purposes	9	Blumenfeld et al. 2000; Cohen and Ball 2006; Earle 2002; Ertmer and Ottenbreit-Leftwich 2010; Fishman et al. 2004; Hew and Brush 2007; Kay et al. 2009; Keengwe and Onchwari 2008; Rogers 2000; Zhao and Frank 2003
Teacher Attitudes and Perceptions	How teachers feel about working with technology, Ranging from user experience to the motivation to consider and try new technologies	9	Beggs 2000; Blumenfeld et al. 2000; Earle 2002; Ertmer and Ottenbreit-Leftwich 2010; Hew and Brush 2007; Groves and Zemel 2000; Keengwe and Onchwari 2008; Rogers 2000; Zhao and Frank 2003
Learnability	How much time it will take to learn and use the technology effectively for pedagogical purposes	9	Beggs 2000; Cuban et al. 2001; Earle 2002; Fishman et al. 2004; Hew and Brush 2007; Groves and Zemel 2000; Kay et al. 2009; Keengwe and Onchwari 2008; Wilson et al. 2000
Integration of Curriculum and Technology	How much the technology aids the accomplishment of curriculum goals	8	Beggs 2000; Blumenfeld et al. 2000; Douglas et al. 2008; Earle 2002; Fishman et al. 2004; Groves and Zemel 2000; Keengwe and Onchwari 2008; Wilson et al. 2000
Administrative Support	Funding opportunities, reassurance and autonomy to use technology	8	Beggs 2000; Blumenfeld et al. 2000; Butler and Sellbom 2002; Earle 2002; Fishman et al. 2004; Hew and Brush 2007; Groves and Zemel 2000; Wilson et al. 2000
Ease of Use	Technology that is generally considered easy to learn and effective for pedagogical purposes	6	Beggs 2000; Butler and Sellbom 2002; Cohen and Ball 2006; Fishman et al. 2004; Groves and Zemel 2000; Wilson et al. 2000
Political Support	Endorsement and proactive Administrative policies that Support the use of technology in schools	5	Blumenfeld et al. 2000; Cohen and Ball 2006; Douglas et al. 2008; Fishman et al. 2004; Wilson et al. 2000
Quality of Available Technologies	Technologies that endure and satisfy the needs of school users	5	Blumenfeld et al. 2000; Cuban et al. 2001; Fishman et al. 2004; Hew and Brush 2007; Keengwe and Onchwari 2008

learning technologies such as robotics, microcontrollers and mechanical construction kits, suggest that these technologies struggle with barriers similar to those already identified in the current literature. Table7.1 shows the top ten barriers founded in the analyzed publications from most frequently noted to least. Obviously, designers of learning technologies can have little to no influence on some of the identified barriers, such as political and administrative support. Yet the majority of the listed barriers should be considered at the products initial design phase.

7.4 Research Methodologies

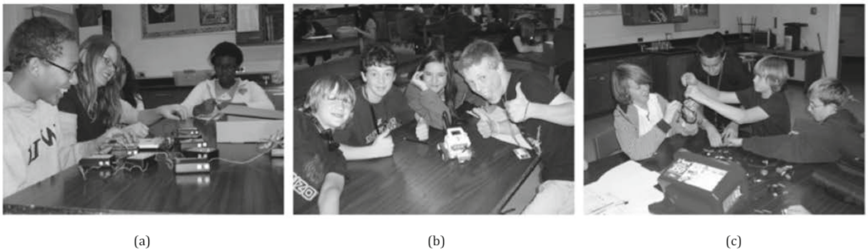
We carried out an 18 hour intervention to expose teachers and students to a variety of learning technologies. Our aim was to observe and record participants perceptions about the use of technologies and the non-functional factors that might attract or detract participants from employing these technologies on a regular basis. Our work relies on three research methods: participant observation, student assessment and teacher interviews.

The study was performed with two groups of 7th grade students in an urban middle school in Tucson, AZ. We had no influence in dividing subjects into groups; the host school had already done this. Group A was composed of 22 students, while Group B contained 26 students. We devoted 9 one-hour sessions to work with each group. Students in both groups had average intellectual abilities and were diverse with respect to race, gender, socio-economic status, and achievement levels. The average age was 13 years old.

Both groups were taught engineering concepts and practices using different teaching methods commonly used in precollege education. Our motivation for using different teaching methods was not to render conclusions regarding the advantages of one method over the other but rather to reveal common issues linked to non-functional requirements regardless of the technology. Our intent was to employ learning technologies to teach concepts that span a spectrum of engineering tenets. The concepts of interest are (1) Systems, (2) Subsystems, (3) Process, (4) Control, (5) Feedback, (6) System inputs, (7) System Outputs, (8) Requirements Elicitation, (9) Optimization, and (10) Trade-offs. To foster a natural environment, each session was led by the same researcher and same participant teacher throughout the study. The host school provided a science classroom equipped with one computer for the teacher, three computers shared between all students, and an overhead projector.

7.4.1 Participant Observation

Participant observation is a contextual technique for the elicitation of system requirements. One of its advantages is that the researcher gains an insider view of the interactions in the location of interest (Jorgensen 1989). Additionally, participant



(a) (b) (c)

Fig. 7.2 Group A working with a variety of learning technologies, (a) eBlocks and integrated circuits on breadboards, (b) LEGO Mindstorms robot, (c) Ferris wheel built with KNEX

observation exposes aspects of ordinary use that are difficult to capture using traditional requirement elicitation techniques and can reveal a more empathetic view of the users experience (Wright and McCarthy 2008). Our observation was overt (i.e., the participants were aware of the researcher role within the natural setting) and detailed field notes were recorded at the end of each one-hour session.

The research team collected data using quantitative and qualitative methods. The main advantage of qualitative methods is that they force the researcher to delve into the complexity of the problem rather than abstract it away (Seaman 1999). While the benefits of qualitative methods to elicit quality requirements and constraints are well defined, results can be difficult to summarize and are frequently considered softer or fuzzier (Seaman 1999). In contrast, quantitative techniques provide researchers with hard or precise results but can fail to capture the details of a phenomenon. While our study relies heavily on qualitative research, we employed quantitative methods to explain some aspects of our findings. Objective and subjective measures of usability are valuable for researchers particularly when researchers have to interpret, compare and relate data, as these different evaluation methods could suggest inconsistent results (Creswell and Plano Clark 2011; Hornbaek 2006).

Group A was presented with a conventional teaching method, in which each session focused on the presentation of an engineering concept. Then the concept was reinforced either through a learning activity or through a demonstration provided by the participant teacher or researcher . The learning activities required students to interact with one another through a hands-on task while following cookbook style instructions (Fig.7.2). The technologies used with Group A were: 1) integrated circuits and electric components on breadboards* (Logic gates, LEDs, resistors, and push buttons), 2) eBlocks* (Phalke and Lysecky 2010), 3) the MicroBug BEAM bot (Velleman 2011), 4) LEGO Mindstorms (Lego 2011), 5) KNEX* construction kits (KNEX 2012). Additionally, each student in Group A participated in a writing competition in which they had to provide a solution to an engineering problem that required formal reasoning about the technical concepts and practices introduced during the intervention period.

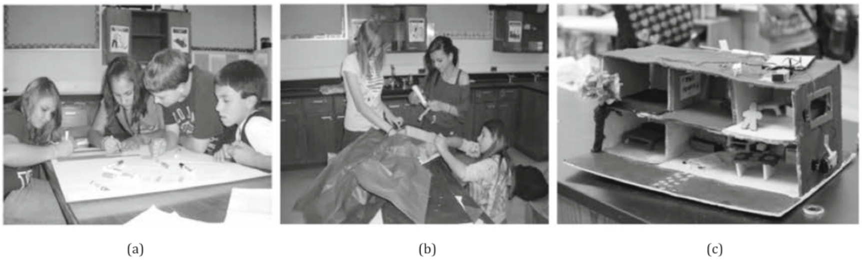


Fig. 7.3 Group B working in a long-term competition project, (a) from drafting a plan to construct a model to (b) construction of a final smart home enhanced with sensors and actuators

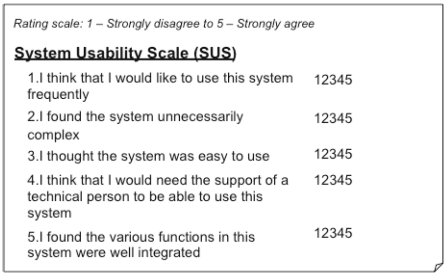
A long-term competition project was used with students in Group B, where students, in groups of four to five, built a scale model of a smart-home for a hypothetical family (Fig.7.3). Each team was provided with a story line that described the family members and their respective life styles. Teams were also provided with an initial amount of tokens, which could be exchanged for construction material or electrical components for use in their models. Teams could win extra tokens during the intervention by completing mini-challenges such as correctly answering questions in a quiz covering the engineering topics taught in previous sessions. Using standard sensors and actuators, battery- and solar-powered lights, and stepper motors, students had the opportunity to build small electronic systems within their smart home models. At the end of the intervention students participated in a science fair style presentation and were evaluated on the basis of creativity, aesthetics, cost (number of tokens spent in each project), and functionality.

7.4.2 Assessment of Engineering Concepts

An assessment questionnaire composed of ten open-ended questions was developed to evaluate participants engineering knowledge. We were of course interested in whether these learning technologies helped student learning, as well as usability and accessibility issues. However, due to absences, not all the participants were able to accomplish both pre- and post-assessments. Our findings only include data obtained from subjects that completed at least 80% of the sessions.

7.4.3 Teacher Interviews

To understand critical quality requirements such as usability and user experience issues (UX) a series of interviews with the participant teacher were conducted



Rating scale: 1 – Strongly disagree to 5 – Strongly agree

System Usability Scale (SUS)

1.I think that I would like to use this system frequently	12345
2.I found the system unnecessarily complex	12345
3.I thought the system was easy to use	12345
4.I think that I would need the support of a technical person to be able to use this system	12345
5.I found the various functions in this system were well integrated	12345

Fig. 7.4 Sample of items included in the SUS scale

throughout the intervention period. Usability encompasses how easily a technology can be employed and how appropriate it is for a particular purpose (Brooke 1996). User experience is an aspect of usability and includes factors such as affect, emotion, fun, aesthetics, and flow (Law 2011). Traditionally usability is measured quantitatively through scaled instruments while UX requires qualitative research. Therefore, we employed two research methods to collect data for both constructs: usability and UX. For the former we conducted a structured interview based on the items of a widely used and validated scale. For the latter, we used an unstructured interview.

The participant teacher has worked at the middle school level for 20 years, 18 as a science teacher. Moreover, she serves as the schools Science Facilitator and is responsible for training incoming science teachers and disseminating the state-of-the-art in science education within her school. The teacher identified herself as a digital immigrant, a term applied to describe subjects who did not grow up in a ubiquitous digital environment and who have learned skills to adapt to technologies broadly used and often considered essential by digital natives. Immigrants of different cultures adapt to new cultures at different paces and degrees, but usually retain traits from their old cultures, for example, an accent. Likewise, digital immigrants show traits that distinguish them from natives including how much they take advantage of technologies in their daily lives and their job duties (Prensky 2001). However, we urge caution in indiscriminately using the terms digital immigrants to describe teachers and digital natives to describe students, as recent studies suggest these assumptions could lead to stereotypes with negative implications for education (Bennet et al. 2009).

The participant teacher responded to a brief set of questions at the end of each session regarding the usability of the technologies employed during the session. This set of interviews was based on the items of the System Usability Scale (SUS) (Brooke 1996). SUS is a technology independent usability survey scale for evaluating a wide variety of software or hardware systems. It consists of ten items and provides a reference score that can be mapped to adjective ratings and acceptability categories (Bangor et al. 2008). The SUS scale was chosen because its items have been assessed for reliability and validity (Bangor et al. 2008; Brooke 1996). Fig.7.4 provides a sample of items included in the SUS scale.

Research instruments consisting of close-ended items such as the SUS scale can be very effective when comparing two prototypes of the same invention. However when close-ended items are used to compare satisfaction with different inventions, we recommend following every item in the instrument with an open question that prompts the respondent to elaborate on their response. This practice lets the requirements elicitor learn about factors that influence the context of use. For example, item 3 in the SUS scale (Fig. 4) seeks to measure Ease of us. However, simply providing a number is not enough to understand which factors influenced why a particular score was given for the evaluated technology.

A final unstructured interview with the participant teacher was carried out to better understand UX aspects not covered in the SUS usability scale. These UX aspects will help to define parameters for a general model to develop usable learning technologies for a wide range of teachers and students. While our example comes from a middle school in Tucson, the outcomes are not intended to be directly applicable for all public middle schools in the United States. Rather, they suggest how the quality model provided in Section 6 can serve as a general guiding tool for the effective development of high quality, accessible learning technologies.

7.5 Findings

7.5.1 Outcomes of Assessment of Engineering Concepts

To draw any conclusions regarding the requirements of learning technologies, it is critical to establish that students actually learn during the intervention. To that end, dependent t-tests of pre- and post-assessments were performed to determine the significance of learning in each group. As shown in Table 7.2, both groups showed a significant difference between pre- and post- assessments.

Table 7.2 Significance of learning outcomes in Group A and Group B

Group A		
Pre-assessments	M = 2.16	SD = 1.39
Post-assessments	M = 3.75	SD = 2.04
t(13) = -4.37		
p 0.001		
Group B		
Pre-assessments	M = 1.46	SD = 1.13
Post-assessments	M = 3.42	SD = 1.18
t(18) = - 4.76		
p = 0.005		

The statistical analysis suggests that participants were able to learn basic engineering concepts both through using a traditional methodology (Group A) and through participating in a long-term project (Group B). In general, higher quality responses were obtained from Group B in that a greater percentage of members of Group B provided more sophisticated conceptual answers than Group A. However, an independent t-study of the quality of answers provided by both groups showed no significant differences.

7.5.2 Outcomes of Structured Interviews

Table7.3 shows the adjective ratings provided by the participating teacher to each of the learning technologies utilized during the intervention. The adjective-based ratings are calculated from the teachers answers to the SUS scale (Bangor et al. 2008). Since the power of the SUS scale relies on the number of subjects answering the questions, a limitation of our study is that only one subject, the participant teacher, answered the SUS questionnaire. Therefore, the presented scores should not be used to infer advantages of one technology over another. Nonetheless, the results served as a measure of the technologies usability within the scope of our intervention. After mapping the SUS scale scores to their corresponding rating adjectives, the results show that KNEX (2012), a construction set consisting of bricks, rods, wheels, gears and connectors, was perceived as an excellent learning technology (Fig. 2c). We prompted the teacher to elaborate on her decision to rate this particular technology higher than the rest. She was very clear in pointing out that even though the mapping of scores to rating adjectives show an Excellent result, she would not consider the technology as Excellent. In retrospect she felt her higher ratings for KNEX could have been influenced by the simplicity of the product and the fact that she saw several ways to use it for teaching purposes. She also articulated her concern that although KNEX was easy to use, it might be limited to teaching simple concepts in short-term projects. She expressed doubt that it would be an effective tool for teaching complex engineering concepts.

Table 7.3 Usability SUS scores and adjective ratings for engineering learning technologies

Technology	SUS Score	Rating Adjective
Integrated Circuits and Breadboards	13.5	Worst Imaginable
eBlocks	51.7	Acceptable
Microbug	31.5	Poor/ Worst Imaginable
Lego Mindstorms	54	Good
K’NEX	76.5	Excellent
Standard Sensors, Actuators and Power Sources	54	Good

In contrast, the participant teacher was very interested in the Lego Mindstorms (2011), one of the most popular robotics kits for young users (Fig. 2b). However, the teacher felt she would need the support of a technical person to learn how to use the technology as well as needing more access to the schools computer lab. She also expressed doubt that the monetary resources to acquire enough Mindstorms kits for her class were available in her school.

The eBlocks educational kits (Phalke and Lysecky 2010), shown in Fig. 2a, are composed of a set of fixed function blocks that enable non-expert construction of embedded system applications. In this case the teacher was satisfied with how easy the eBlocks were to learn for herself and the students. Her main concern was with the robustness of the current prototype, as some of the eBlocks broke while students where using them and there was no easy way to repair them on-site.

Standard sensors, actuators and power sources were rated higher than we expected. The teacher perceived it advantageous to expose students to standard electrical components such as push buttons, switches, potentiometers, servomotors, LEDs, solar cells and batteries. Additionally, these components could be adapted so the students could connect them using only crimp pliers and butt connectors as opposed to a soldering gun.

The MicroBug (Vellman Inc 2011) is an example of BEAM bots used by hobbyists and sometimes educators. BEAM bots are composed of low-cost electronic components, so their acquisition cost is lower than most robotic alternatives. However, two disadvantages of using BEAM bots are that the components usually need to be soldered together, and once the final product is built, it is difficult to take the robot apart to reuse its components in later projects. The teacher commented that the high supervision required when students are using soldering guns or similar tools could not be provided in a regular day. She also felt that since she could only supervise a small number of students at one time while working with the MicroBug, employing the technology could easily lead to classroom management problems.

The use of integrated circuits and breadboards was the least popular for both the teacher and students. The teachers frustration while working with integrated circuits and breadboards was clear during the intervention. For example, when students were unable to follow basic instructions to use AND and OR gates to turn LEDs on and off, they lost their engagement with the activity, and were unable to keep themselves on-task. In this case, the teachers negative score can be attributed to the students response to the activity.

7.5.3 Outcomes of Unstructured Interview

The main objective of the unstructured interview was to understand the compromises a teacher faces when deciding to acquire a dedicated learning technology or develop their own lesson plans with other technologies not specifically designed for

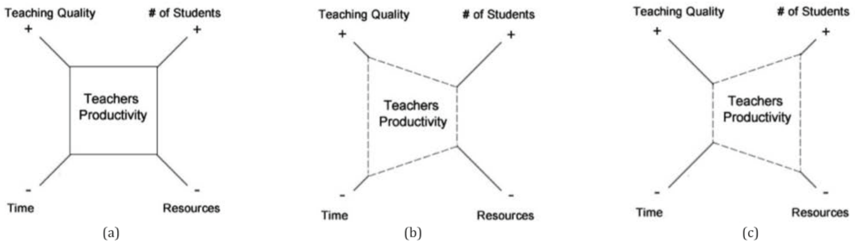


Fig. 7.5 Explaining teachers productivity in precollege engineering education through the Devils square. (a) A compromise scenario between competitive factors (b) Teachers perception of productivity using learning technologies (b) Teachers perception of productivity using non-dedicated technologies

education purposes (non-dedicated technologies). As expected, several constraints elicited from the teacher have already been identified in previous works (Table7.1), specifically, (1) limited access to the computer lab, (2) funding, (3) quality of technical support, (4) ongoing education, and (5) basic engineering education.

Limited access to the computer lab. Like other teachers in the school (35 teachers in all) the participant teacher has to reserve the computer lab every time she wants to use it for her class. The result is that she can only use the computer lab 2 days per school quarter (a 45 day period), not enough time for students to work on long-term engineering projects.

Funding. Funding to purchase any type of technology is scarce and competitive. Though several mini-grant programs are available, writing these grants requires considerable time outside of school hours. Not surprisingly, teachers are easily discouraged from submission when one or a few of their applications are denied.

Quality of technical support. Teachers at the host school generally feel deserted with regard to technical support. The participant teacher shared with us that in her school it sometimes takes over a month to get technical help. Therefore when technical issues arise, teachers have little recourse but to try to figure out and fix the problems themselves.

Accessible Training. Teachers also experience as a challenge access to training in using new learning technologies. Though technology vendors usually offer workshops and courses at special rates to practitioner teachers, these rates are typically be covered by the teacher instead of the school they work for.

Basic Engineering Education. Curriculum is certainly available for many commercial products; however there is a need for open-source engineering curriculum that describes engineering concepts in age-appropriate ways apart from a particular learning technology. Such materials would enable teachers (and students) to understand engineering principles at a higher level, and to relate engineering to other disciplines such as science and math. In addition, such materials would enable teachers to feel more comfortable at designing their own lessons using available resources.

Regardless of the challenges identified, teachers in the host school are largely interested in using learning technologies in their classrooms. The salient point of the interview was the teachers reasoning for making decisions about acquiring a learning technology. She was highly influenced by what she perceives as teacher productivity, defined as the ability to teach quality concepts in a shorter time; given the resources the teacher has access to in her school. Success in using learning technologies in precollege engineering education can be seen as a trade-off between four key factors: 1) the percentage of students within the classroom that receive hands-on-experience with the technology. For example, when a limited number of computers are provided, some students tend to own the technology while others passively observe them or engage in other non-productive activities; 2) the resources required to use the learning technology, including acquisition cost, physical space, technical support, need of computers or Internet access, etc.; 3) the quality of teaching enabled by the technology, evaluated by the breadth and depth of concepts that can be taught, and 4) the time beyond paid work hours teachers need to invest to prepare a teaching session.

The teachers reasoning is explained by using a model known as the Devils Square, which was originally developed to understand the productivity of software engineers (Sneed 1989). We have adapted this model to explain the teachers perceived productivity during the intervention period (Fig.7.5a). The four corners of the Devils square represent desired but competitive factors that had to be balanced by the instructor while using learning technologies. In principle, it is desirable to maximize the factors positioned at the squares upper corners, while minimizing the factors positioned at the lower corners. In a balanced scenario, the teachers productivity is represented as an inner square; this means that the four competitive factors have been evenly balanced. The teachers productivity is considered a constant, meaning that it will always cover the same area inside the outer square regardless of whether its shape is a square, a parallelogram, or a triangle. The shape of the inner figure depends on how the teacher finds a balance between the identified competitor factors.

During the intervention, we worked with dedicated learning technologies (Group A) as well as built a lesson plan which relies on technologies not specifically designed for educational purposes (Group B). Dedicated learning technologies (e.g. Mindstorms) minimize the preparation time teachers need to invest in planning a lesson (these products are regularly accompanied by rich curriculum) and maximize the quality of learning but require significant resources. Therefore, with the exception of technology-rich schools, only a small percentage of students will have the opportunity to work directly with the technology (Fig.7.5b).

In comparison, developing engineering lessons with technology not specifically designed for educational purposes (e.g. standard sensors, actuators and power sources) can be time consuming, as many of these technologies have to be adapted by the teachers before these technologies can be used in the classroom. Additionally teachers have to invest time crafting effective lessons plans (Fig.7.5c). On the other hand, non-dedicated learning technologies can be acquired in high volume at a modest price, allowing more students to have hands-on experiences. However, the

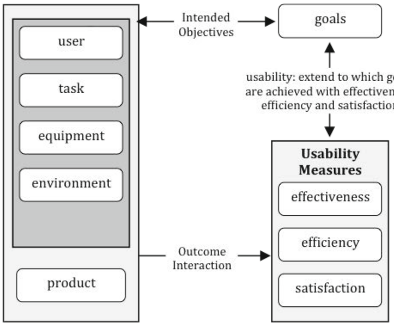


Fig. 7.6 ISO 9241-11 (1998) Usability Framework

quality of teaching and learning can be limited by the affordances of non-dedicated technology i.e., the strengths and weaknesses of technologies with respect to the possibilities they offer the people that might use them (Gaver 1991). Moreover non-dedicated technologies require a significant cognitive load from teachers because the effectiveness of these technologies are highly dependent on the teachers ability to use them in a constructive way.

Clearly the optimum scenario entails teachers using technologies that maximize their teaching quality and allow significant numbers of students to have hands-on experience, while minimizing the time teachers must invest after hours in preparing curriculum and remaining economically feasible for a given school.

7.6 A Basic Model for the Development and Adaptation of Learning Technologies

Considering the precollege community as a uniform market for learning technologies is an unsustainable notion. There are inequalities in the level of constraints, ICT, and resources available. While reports from institutions such as the National Center of Education Statistics (NCES) (Gary et al. 2008) are useful to keep track of progress relating to the distribution of technology at a macro-level, they can be misleading if interpreted as an indicator of ICT integration at the meso- and micro-levels of educational settings. In our experience, the use of ICT resources at our host school differed considerable from what the NCES data may have led one to expect.

7.6.1 Quality Requirements

General guiding tools are needed to capture quality requirements in the domain of learning technologies. An adapted version of the usability model proposed by the

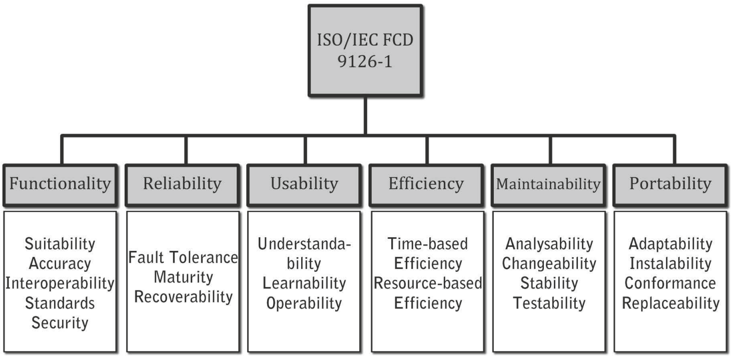


Fig. 7.7 The ISO/IEC FCD 9126-1 (1998) quality model to evaluate quality-in-use

International Organization for Standardization, ISO 9241-11 (1998) (Fig.7.6), and the quality model included in ISO/IE 9126-1 (1998) (Fig.7.7) can serve to enumerate the requirements sought in learning technologies by stakeholders.

The ISO 9241-11 usability framework was developed to define usability for hardware-software systems. It strives to facilitate the design not only of technical functional products, but also products that are usable by consumers. The framework comprises three main elements: a description of intended goals, usability measures such as effectiveness, efficiency and satisfaction, and a description of the context of use, which encompasses user expertise, tasks necessary to achieve a goal, available equipment, and the social and physical environment where the system will be used. Effectiveness is a measure of how well users achieve specified goals and reflects the resources expended in meeting the user specified goals, while satisfaction addresses user attitudes towards the product.

The literature analysis and participant observation suggest that there exist clusters of schools, which share goals and operate in contexts that lead to similar usability challenges. For example, most of the research literature cited in Section 3 focuses on contexts within the US school system and that of other high-income countries. Schools that share similar characteristics may be able to directly apply the findings of these works. However, the findings may not be applicable for resource-constrained schools. Likewise, there could be different school clusters coexisting in a country, for example clusters can be defined by community type such as urban versus rural. Educational policies also play a role in dividing schools clusters as national and local standards may differ from country to country and state to state. Other factors to take into account are social, political and cultural norms. In sum, schools within a given cluster or category share fundamental structural factors and have common issues regarding learning environment; examples of these factors are provided in Fig.7.8.

Rather than designing products for pre-college engineering instruction with a single model in mind, we believe that educational products will be more successful if the wide variety of school characteristics is taken into account in the early planning

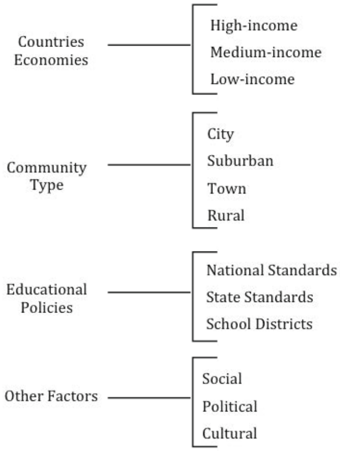


Fig. 7.8 Factors that can determine school clusters

stages. The result will be customized versions of general quality models, based on the target school cluster, that ensure the inheritance of crucial attributes from the parent model.

Many of the quality requirements elicited during our research align with the requirements included in the ISO 9126-1 quality model (Fig.7.7). While the ISO 9126-1 is a general quality framework intended for evaluating software systems, it does not prescribe specific requirements, which makes it malleable enough to be used in other domains through applying a customization process (Behkamal et al. 2009; Chua and Dyson 2004). The customization process is key to successfully using general quality models in a specific domain. Our model provides the means to facilitate customization by analyzing the factors or parameters that affect the usability and UX of students and teachers using learning technologies for engineering education.

7.6.2 Determining Quality-in-Use of Engineering Learning Technologies

We have chosen the ISO 9126-1 as an example of a general model because of its high recognition, adaptability and validity. The ISO 9126-1 (1998) quality model comprises by six product characteristics that are further divided into subcategories. Functionality describes needs of the platform. Reliability relates to the capability of the product to maintain its performance over time. Usability evaluates the effort required by the end user or set of end users. Efficiency relates to the relationship between the performance of the product and the amount of the resources used to obtain the desired performance. Maintainability describes the effort needed to modify

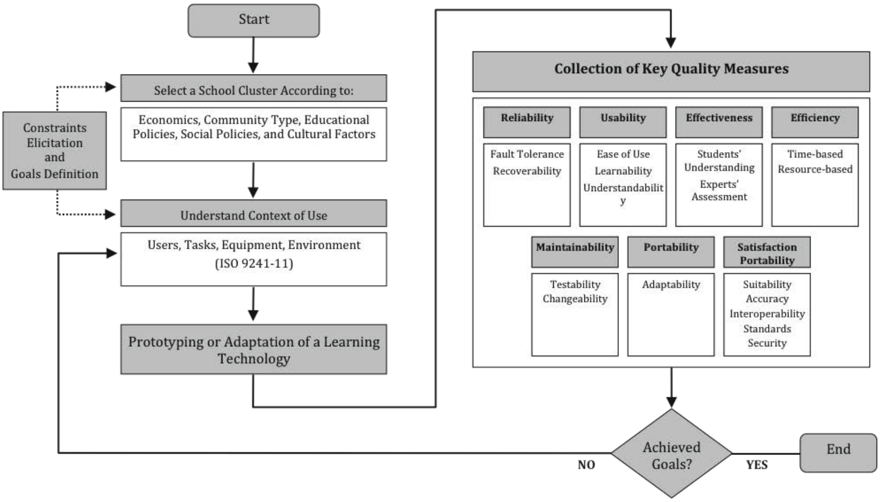


Fig. 7.9 Basic model for the development and adaptation of learning technologies

the platform. Portability indicates the ability of the platform to move across environments.

Learning technology products that meet these quality requirements should facilitate quality-in-use for stakeholders. Both teachers and students benefit from the functionality, reliability, usability and efficiency of the product. Technical support benefits from the maintainability requirements. The school benefits from the product portability requirement since, as the shared resource can move across a variety of classrooms without dedicated ICT requirements. Using a customized model based on the ISO 9241-11 and ISO/IE 9126-1 as a guiding tool to achieve usability expectations and quality-in-use can facilitate adoption of engineering instruction technologies (Fig.7.9).

Identify representative school cluster

The avenue to assessing engineering learning technologies starts by tackling the barriers of usability, adoption and sustainability at the classroom and school level. Schools can be categorized in terms of their goals, needs, and constraints. Any one size fits all product will inevitably preclude some school clusters from acquiring the technology and in other cases schools might be prevented from taking full advantage of their ICT resources. Instead, we believe that our goal oriented requirements engineering approach, which acknowledges the differences in constraints and quality requirements among school types, is a more promising approach.

Apply goal oriented requirements engineering elicitation techniques

Once a cohesive school cluster has been recognized, it is imperative for the requirements engineer to identify the stakeholders and their needs in relation to the system-to-be. Common stakeholders are teachers, students, administrators, technical personnel and political and social organizations (e.g. school board). Numerous methodologies are available for the elicitations of requirements and stakeholders needs, including but not limited to, traditional techniques such as questionnaires, surveys, and interviews; group elicitation techniques such as brainstorming and focus groups; prototyping, or: presenting a prototype to a potential group of customers to stimulate discussion for group elicitation; and contextual techniques, i.e. ethnographic techniques like participant observation (Nuseibeh and Easterbrook 2000).

Adopt and customize a general quality model A definition of usability that highlights the context of use by linking users, tasks, equipment and environment is needed. The ISO 9241-11 model (Fig.7.6) is one such option. The model for usability measures (Hornbaek 2006) is another option, in which the usability measures of effectiveness, efficiency and satisfaction in the ISO 9241-11 are replaced by outcomes, interaction process and user attitudes and experiences. The outcomes aspect captures the users perceptions of whether the intended outcomes were reached.The interaction process focuses on the users experience, while user attitudes and experiences captures the users attitude to that experience.

Determine critical measures of quality-in-use for learning technologies The measures for quality-in-use provided by a general model should not be weighted equally for every system-to-be. Rather, specific content domains such as accounting software, programming environments, domestic appliances, and learning technologies place emphasis on different aspects of quality-in-use. Methods are available to rate the importance of the individual quality metrics when general models are applied to specific domains (Behkamal et al. 2009). A common issue associated with the use of general quality models across various domains lies in the interpretation of the measures. For example, in the education domain, high task-completion times can be indicators of students engagement and motivation while in domains where worker productivity is crucial, high task-completion times might be unacceptable (Behkamal et al. 2009). It is critical for the requirements engineers to adequately define how each measure will be construed to avoid interpretation errors during the design and evaluation process.

This paper provides a fundamental but not exhaustive list of measures to determine quality-in-use of learning technologies for engineering education. These measure are categorized as measures of reliability, usability, effectiveness, efficiency, maintainability, portability and satisfaction.

Measures of Reliability address the ability of the learning technology to keep functioning consistently as expected over time. Fault Tolerance reflects the robustness of a learning technology across different levels of usage, indicated by the average time that takes a technology to fail. Recoverability captures a technologys ability to be restored to a functional state preferably the same state as before the failure occurred and evaluates both the recovery time needed to restore the system as well as the recovered state.

Measures of Usability addresses how easily a technology can be employed and how appropriate it is for a given purpose. Specifically, Ease of use considers cognitive challenges independent of the subject matter, emphasizing how important it is for learning technologies to eliminate details and steps that prevent users from learning the core subject contents. Papert (1980) and Resnick et al (2009) explained ease of use in the domain of programming languages for children as having low floors the trait of a programming language that allows users to get started programming algorithms easily. Equally important are the traits of high ceilings and wide walls, referring to the technologys affordance to allow its users to increase the complexity of end products, provide opportunities for exploring a diversity of topics, and accommodate different learning styles. Developers can gauge the ease of use of a particular learning technology through direct observation, thinking-out-loud techniques, interviews and retrospective questionnaires. Learnability refers to the ability of the system-to-be to provide resources for teachers and students that are perceived as a learning on your own experience. For example, in our intervention, the teachers interest in the Lego Mindstorms was tempered by her perception that she would need to attend a specialized course to use the technology. A variety of collection methods such as interviews, direct observation and timing techniques can help to gauge the learnability of the platform. Lastly,

Understandability refers to the necessity of a learning technology being clear to the users and designed to prevent mistakes. Usability can be described quantitatively as the number of affordances used by students and teachers divided by the total number of affordances offered by a given learning technology.

Measures of Effectiveness determine if the employment of a technology facilitates the learning of engineering concepts and practices. First, Measures of student understanding indicate if the system facilitates the students conceptual and procedural understanding of the topic domain. For the assessment of procedural knowledge, retrospective interviews and thinking-out-loud approaches are recommended. The assessment of conceptual knowledge can be achieved by analyzing the quality of students answers to open-ended questions. Next, an Expert assessment helps to evaluate student artifacts produced as a result of this learning technology (Hornbaek 2006). In the intervention presented in previous sections, engineering faculty and graduate students were recruited to evaluate the end products developed by students essays and smart home models. The engineering experts who assessed the artifacts also served as a knowledge source to improve the technology in accordance with its educational goals.

Measures of Efficiency evaluate how human intellectual and physical resources are spent to achieve a meaningful understanding of the content domain. Time-based Efficiency can be evaluated simply by recording the set-up time to use the learning technology in the classroom and the time needed to clear the working space. In contrast, Resource-based efficiency assesses the ability of the targeted school cluster to take advantage of their ICT resources. The number of students concurrently interacting with a given technology without a teachers direct supervision is also a good measure of this metric.

Measures of Maintainability capture the effort required to diagnose and troubleshoot a learning technology on-site. Testability enables users to verify if the system is working appropriately and provides meaningful status cues when the technology is failing. Interacting with users and recording the interpretability of the cues provided by the system when in failure or non-optimal status is a good measure of this metric. Changeability denotes the ability of a user to modify the technology to better support their learning goals in an effortless and cost-effective way.

Observing a user modify or replace one aspect of a learning technology is one method to evaluate the changeability of a given platform.

Measurements of Portability are paramount in educational settings, especially for schools constrained by inadequate ICT resources or classroom space. The ability to use the learning technology in a diversity of learning environments facilitates the scalability of the product to wider audiences. Adaptability refers to how the learning technology can be changed to satisfy constraints imposed by different learning environments. It can be assessed by dividing the number of educational experiences possible in a particular learning environment by the number of experiences possible in an ideal environment.

Measures of Satisfaction reflect the perceptions of teachers and students towards using a technology. Satisfaction relates to the users experiences and how the outcomes of such experiences are recalled. Satisfaction is usually assessed through questionnaires, attitude rating scales, ranking tables and open interviews. Preference measures should be used with both teachers and students, since they might have different needs and priorities. Measuring the Perception of Outcomes is also crucial to demonstrating the learning advantages provided by a given technology. Improvements in knowledge and understanding need to be obvious to the teachers and students, and based on quantitative evidence so that the investment of resources can be justified.

7.7 Discussion

The experience of working alongside a teacher in a typical school environment has enabled a better understanding of the challenges faced by teachers using a variety of learning technologies. The path to assessing the usability of engineering learning technologies is long and beset with challenges. Achieving technical functionality is not enough; we must seek out solutions with broad applicability across a variety of learning environments. While designing high-end products has benefits, there remain many obstacles in obtaining these technologies and effectively utilizing them. We propose tackling the problem by first developing notions of school clusters, characterized by similarities in available resources and constraints. Second, we propose adopting a requirements engineering approach that focuses on quality-in-use, employing general usability and quality models with key usability and quality measures specific to the domain of precollege engineering education. The proposed model is by no means complete and mature, but is a step towards requirements specifications that support the development of more inclusive learning technologies for precollege engineering education. To further corroborate the suggested strategies, future research might focus on different types of school clusters as well as further evaluation of needs identified within the same cluster. We look forward to further research that strengthens, refines, and expands this work.

References

1. Bangor, A., Kortum, P., Miller, J.: An Empirical Evaluation of the System Usability Scale. Journal of Human-Computer Interaction 24(6), 574–594 (2008)
2. Beggs, T.A.: Influences and Barriers to the Adoption of Instructional Technology. In: Proceedings of the Mid-South Instructional Technology Conference, Murfreesboro, TN (2000)
3. Behkamal, B., Kahani, M., Kazem Akbari, M.: Customizing ISO 9126 quality model for evaluation of B2B applications. Information and Software Technology (51), 599-609 (2009)
4. Bennet, S., Maton, K., Kermit, L.: The ‘digital natives’ debate: a critical review of the evidence. British Journal of Educational Technology (39), 775–786 (2008)
5. Bevan, N.: Measuring usability as quality of use. Software Quality Journal (4), 115–150 (1995)
6. Bevan, N.: Quality in Use: Meeting User Needs for Quality. Journal of Systems and Software (49), 89–96 (1999)
7. Blumenfeld, P., Fishman, B., Krajcik, J., Marx, R.W., Solloway, E.: Creating Usable Innovations in Systemic Reform: Scaling Up Technology-Embedded Project-Based Science in Urban Schools. Educational Psychology 35(3), 149–164 (2000)
8. Brooke, J.: SUS: A ‘quick and dirty’ usability scale, Usability Evaluation in Industry. Taylor and Francis, London (1996)
9. Butler, D., Sellbom, M.: Barriers to Adoption Technology for Teaching and Learning. Education Quarterly 25(2), 22–28 (2002)
10. Robotics Academy, Carnegie Mellon Robotics Academy (2010), `http://www.education.rec.ri.cmu.edu`
11. Chua, B., Dyson, L.: Applying the ISO9126 model to the evaluation of an e-learning system. In: Proceedings of the Australian Society for Computers in Learning Tertiary Education (ASCILITE) Conference, Perth, Australia, pp. 184–190 (2004)
12. Cohen, D., Ball, D.: Educational innovation and the problem of scale. In: Scale-Up In Education: Ideas In Principle. Rowman and Littlefield Publishers, Lanham (2006)
13. National Research Council, A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academies Press, Washington, DC (2011)
14. Creswell, J.W., Plano Clark, V.L.: Designing and Conducting Mixed Methods Research, 2nd edn. SAGE Publications Inc., Thousand Oaks (2011)
15. Cuban, L., Kirkpatrick, H., Peck, C.: High Access and Low Use of Technologies in High School Classrooms: Explaining an Apparent Paradox. American Educational Research Journal 38(4), 813–834 (2001)
16. Douglas, S., Christensen, M., Orsak, G.: Designing Pre-College Engineering Curricula and Technology: Lessons Learned from the Infinity Project. Proceedings of the IEEE 96(6), 1035–1048 (2008)
17. Earle, R.: The Integration of Instructional Technology into Public Education: Promises and Challenges. ET Magazine 42(1), 5–13 (2002), `http://bookstoread.com/etp/earle.pdf` (retrieved June 24, 2012)
18. Ertmer, P., Ottenbreit-Leftwich, A.: Teacher Technology Change: How Knowledge, Confidence, Beliefs and Culture Intersect. Journal of Research on Technology in Education 42(3), 255–284 (2010)
19. Ferguson, E.: Engineering and the Mind’s Eye. MIT Press (1994)
20. Fishman, B., Marx, R., Blumenfeld, P., Krajcik, J.: Creating a Framework for Research on Systematic Technology Innovations. The Journal of the Learning Sciences 13(1), 43–76 (2004)

21. Hew, K.F., Brush, T.: Integrating Technology into K-12 Teaching and Learning: Current Knowledge Gaps and Recommendations for Future Research. Educational Technology Research Development (55), 223–252 (2007)
22. Foster, P.N.: The Relationship Among Science, Technology and Engineering in K-12 Education. Connecticut Journal of Science Education (42), 48–53 (2005)
23. Gary, L., Thomas, N., Lewis, L.: Educational Technologies in USA public schools: Fall 2008. U.S. Dept. of Education, National Center for Education Statistics, NCES 2010-034 (2008)
24. Gaver, W.: Technology Affordances. In: Proceedings of the Conference on Human Factors in Computing Systems, New Orleans, LA, pp. 79–84 (1991)
25. Glinz, M.: On Non-Functional Requirements. In: Proceedings of the IEEE International Requirements Engineering Conference, New Delhi, India, pp. 21–26 (2007)
26. Grace, J., Kenny, C.: A short review of information and communication technologies and basic education in LDCs- what is useful, what is sustainable? International Journal of Educational Development (23), 627–636 (2003)
27. Groves, M., Zemel, P.C.: Instructional Technology Adoption in Higher Education: an Action Research Case Study. International Journal of Instructional Media 27(1), 57–65 (2000)
28. Hohlfeld, T., Ritzhaupt, A., Barron, A.E., Kemker, K.: Examining the Digital Divide in K-12 Public Schools: Four-year Trends for Supporting ITC Literacy in Florida. Computers and Education (51), 1648–1663 (2008)
29. Hornbaek, K.: Current practice in measuring usability: Challenges to usability studies and research. International Journal of Human Computer Studies (64 2, 79–102 (2006)
30. ISO/IEC, F.C.D.: 9126-1, Software product quality - Part 1: Quality model (1998)
31. ISO 9241-11, Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11 Guidance on usability (1998)
32. Jorgensen, D.L.: Participant Observation: A Methodology for Human Studies. Sage Publications, Thousand Oaks (1989)
33. Katehi, L., Pearson, G., Feder, M.: Engineering in K-12 Education, Understanding the Status and Improving the Prospects. The National Academies Press, Washington D.C. (2009)
34. Kay, R., Knaack, L., Petrarca, D.: Exploring Teachers Perceptions of Web-based Learning Tools. Interdisciplinary Journal of E-Learning and Learning Objects (5), 27–50 (2009)
35. Keengwe, J., Onchwari, G.: Computer Technology Integration and Student Learning: Barriers and Promise. Journal of Science Education and Technology 17(6), 560–565 (2008)
36. K'NEX, The World's Most Creative Construction and Building Toys (2012), `http://www.knex.com`
37. Law, E.L.C.: The Measurability and Predictability of User Experience. In: Proceedings of the Symposium on Engineering Interactive Computing Systems, Pisa, Italy, pp. 1–10 (2011)
38. van Lamsweerde, A.: Goal Oriented Requirements Engineering: A Guide Tour. In: Proceedings of the IEEE International Symposium on Requirements Engineering, Toronto, Canada, pp. 249–261 (2001)
39. Lawson, A.: Teaching Inquiry Science in Middle and Secondary Schools. Sage Publications, Thousand Oaks (2010)
40. LEGO, LEGO Mindstorms (2011), `http://mindstorms.lego.com`
41. Lu, S.C.Y.: Collective rationality of group decisions in collaborative engineering. International Journal of Collaborative Engineering 1(1-2), 38–74 (2009)

42. Margolis, J., Estrella, R., Goode, J., Jellison Holme, J., Nao, K.: Stuck in the Shallow End: Education, Race, and Computing. The MIT Press, Cambridge (2008)
43. Nuseibeh, B., Easterbrook, S.: Requirements engineering: a roadmap. In: Proceedings of the International Conference on Software Engineering, Limerick, Ireland, pp. 35–46 (2000)
44. Papert, S.: Mindstorms: Children, Computers, and Powerful Ideas. Basic Books, New York (1980)
45. Perraton, H., Creed, C.: Applying new technologies and cost-effective delivery systems in basic education. Education for All Secretariat, UNESCO, Paris (2002)
46. Peske, H.G., Haycock, K.: Teaching inequality: How poor and minority students are shortchanged on teacher quality. The Education Trust, Washington, D.C. (2006)
47. Phalke, A., Lysecky, S.: Adapting the eBlock Platform for Middle School STEM Projects: Initial Platform Usability Testing. IEEE Transaction on Learning Technologies 3(2), 152–164 (2010)
48. Prensky, M.: Digital natives, digital immigrants. On the Horizon 9(5), 1–6 (2001)
49. Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., Kafai, Y.: Scratch: Programming for all. Communications of the ACM 52(11), 60–67 (2009)
50. Riojas, M., Lysecky, S., Rozenblit, J.: Educational Technologies for Precollege Engineering Education. IEEE Transactions on Learning Technologies 5(1), 20–37 (2012)
51. Rogers, P.L.: Barriers to Adopting Emerging Technologies in Education. Journal of Educational Computing Research 22(4), 455–472 (2000)
52. Sadler, P., Coyle, H., Schwartz, M.: Engineering Competitions in Middle School Classroom. Journal of the Learning Sciences 9(3), 299–327 (2000)
53. Seaman, C.B.: Qualitative Methods in Empirical Studies of Software Engineering. IEEE Transactions on Software Engineering 25(4), 557–572 (1999)
54. Sheppard, S., Colby, A., Matacangay, K., Sullivan, W.: What is Engineering Practice? International Journal for Engineering Education 22(3), 429–438 (2006)
55. Sneed, H.N.: Software Engineering Management. Ellis Horwood, Chichester (1989)
56. Star, J.R.: On the Relationship Between Knowing and Doing in Procedural Learning. In: Proceedings of the Conference of the Learning Sciences, Ann Arbor, MI, pp. 80–86 (2000)
57. Velleman Inc., Running MicroBug (2011), `http://www.vellemanusa.com`
58. Wilson, B., Sherry, L., et al.: Adoption of Learning Technologies in Schools and Universities. In: Handbook on Information Technonogies for Education and Training, pp. 293–308. Springer, New York (2000)
59. Wright, P., McCarthy, J.: Empathy and Experience in HCI. In: Proceedings of the Conference on Human Factors in Computing Systems (CHI), Florence, Italy, pp. 637–646 (2008)
60. Zhao, Y., Frank, K.A.: Factors Affecting Technology Uses in Schools: An Ecological Perspective. American Educational Research Journal 40(4), 807–840 (2003)