Digital Literacy for All Through Integrative STEM

Leo A. Siiman, Carlos Manuel Pacheco Cortés, and Margus Pedaste

Institute of Education, University of Tartu, Salme 1a, 50103 Tartu, Estonia
margus.pedaste@ut.ee

Abstract. The ever growing importance of digital literacy requires an effective educational strategy to introduce it into K-12 education. We propose teaching digital competences within the context of an integrative STEM framework. An overview of integrative STEM, its two core components (design from the context of technology education and inquiry from science education), and the natural connections to digital literacy are discussed. Two examples are given—robotics and 3-D computer software—as promising digital platforms to implement this strategy. Including digital literacy in integrative STEM offers all K-12 students the opportunity to acquire digital competences.

Keywords: Digital literacy, technology education, integrative STEM, design, inquiry, robotics, 3-D technology.

1 Introduction

The rapid development and widespread proliferation of digital technologies has brought greater conveniences to people in the 21st century. A mobile phone can now instantly retrieve the latest news across the globe or deliver multimedia entertainment experiences. But simply consuming the affordances of technology, without an awareness or understanding of how technology is created or applied, may leave many people unprepared for future challenges and opportunities. New technologies have shown an uncanny ability to automate tasks and replace humans at many jobs. In order to prepare people for the future workplace and improve their capabilities as citizens in daily life, technological and digital literacy must be emphasized in the educational curriculum. But how to include these literacies in today's educational framework while reaching a broad and inclusive audience is not obvious.

In Estonia, it is assumed that digital literacy is acquired through learning in all the different subjects, and a separate subject for learning computing, computers and software, or programming is only optional. However, the results – i.e. the average level of digital literacy in society and students interest to relate their career to ICT in different areas – are still not satisfying, and therefore digital competencies have been declared one out of five strategic goals of the Estonian educational strategy for 2020. Digital competencies are the core of digital literacy and thus there is a need to find new effective approaches to increase digital literacy. We assume that similar problems are faced by many other countries and an approach to acquiring digital literacy where subject-related specific aims are integrated could offer a beneficial solution.

P. Zaphiris and A. Ioannou (Eds.): LCT 2014, Part I, LNCS 8523, pp. 119–127, 2014.

One solution is to integrate digital literacy with STEM education where the inquiry approach has been widely used [1-3], but often not acknowledged by teachers. European level documents have stressed the importance of inquiry based education and regard it as one of the key aims in the future [4]. The current science classroom learning environment is often a mixture of divergent pedagogies and diverse students' orientations or preferences [5, 6]. There is a mismatch between opportunity and action in most education systems today. This revolves around the meaning of 'science education', a term that is often misappropriated in the current school practice, where rather than learning how to think scientifically, students are generally being lectured about science and asked to remember facts [7].

In this contribution we propose embedding digital literacy within an integrative STEM model. The STEM (science, technology, engineering, mathematics) disciplines are regarded as essential for ensuring future economic prosperity [4]. An integrative STEM model attempts to align science and mathematics education with technology and engineering education. Sanders (2009) [8] describes integrative STEM as intentionally combining two approaches: the design approach in technology/engineering education with the inquiry approach in science. We argue that digital literacy fits naturally within the integrative STEM program. Our research question is to investigate how digital literacy can be achieved in integrating inquiry related to science education with design related to technology education. To justify our position we organized this paper as follows. First we consider definitions of digital literacy to identify its key features. Next, the features of inquiry and design are separately summarized and compared to digital literacy. Then a discussion of integrative STEM is given to show its advantages and current challenges. Finally, the inclusion of digital literacy in integrative STEM is explored and two examples—robotics and 3-D computer software—are considered as potential practical implementations.

2 Digital Literacy

One definition of digital literacy comes from a list of recommendations on key competences for lifelong learning by the European Parliament and of the Council of the European Union, where it is stated that

Digital competence involves the confident and critical use of Information Society Technology (IST) for work, leisure and communication. It is underpinned by basic skills in ICT: the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet. (European Union, 2006, p.15 [9])

At present the use of computers and the internet are the key enabling technologies for digital literacy. But in terms of characterizing digital literacy from a wider perspective, Hobbs (2011) [10] offers a list of five essential features to describe digital competencies:

- **Access** – use digital tools and technologies to access information
- **Analyze & Evaluate** – apply higher order thinking skills to process information
- **Create** – practice creative expression with digital technologies

- **Reflect** – engage in reflective thinking
- **Act** – participate and communicate in a social community

This list of competencies shows that digital literacy involves more than technical competency with digital tools. The *Reflect* competency describes a metacognitive process, *Create* implies originality and innovativeness, and *Act* requires social collaboration. Interestingly, many of these descriptions overlap with processes described by the inquiry and design. The inquiry and design approaches are the foundations for integrative STEM. Therefore integrating digital literacy with integrative STEM appears feasible and promising.

At this point it is useful to review the inquiry and design approaches separately before looking at how they merge with each other in integrative STEM.

3 Inquiry

Inquiry-based education is a teaching and learning strategy that promotes engagement and active participation of a learner to discovery knowledge. Recent meta-analysis studies show that inquiry-based instruction results in more beneficial learning than direct forms of instruction like lecturing [11, 12]. In inquiry, students ask questions and generate hypotheses, plan and conduct experiments, interact directly with investigative tools to explore phenomena, and communicate results. Computer-based learning environments have been shown to be especially effective ways to implement inquiry [13].

The inquiry process can be broken down into steps (usually called inquiry phases) to better explain the distinct reasoning processes that comprise inquiry. Inquiry phases originate from the steps found in the scientific method. Even though the scientific method is not a rigidly prescriptive sequence of steps it offers a useful basis for structuring inquiry in education. Mäeots, Pedaste, & Sarapuu (2011) [14] applied a typical list of inquiry phases to research student development of inquiry skills in a computer-based learning environment. The inquiry phases included transformative and regulative activities that should be applied not linearly but in integration:

Phases related to transformative processes:

- **Question** – generate research questions based on a problem
- **Hypothesis** – propose explanations and predictions that can be empirically tested
- **Experiment** – perform tests and collect data to confirm or refute a hypothesis
- **Data analysis** – synthesize new knowledge from experimental outcomes
- **Conclusion** –summarize and communicate results; contemplate future research

Phases related to regulative processes:

- **Planning** – design and schedule the learning process; set performance goals
- **Monitoring** –observe and record the study process
- **Evaluation** – verify that learning goals are achieved; reflect on the process

Comparing inquiry phases with features of digital literacy shows several similarities; such as applying higher order thinking skills, communicating, and reflective thinking. But inquiry sometimes does not explicitly emphasize features such as creativity, mentioned by Hobbs (2011) [10] as an important characteristic of digital literacy. Often the goal of inquiry is to ask a question about a scientific topic that leads to a single correct answer. Although students are challenged to actively discover the answer on their own, the final correct outcome is common to all investigators. In contrast, the design approach allows for open-ended problems where the outcomes can vary between students, yet still solve the original design problem. The design approach is useful for stimulating creativity in students.

4 Design

Design involves solving a practical problem while conforming to a certain set of constraints [15]. It is an iterative process that permits a multitude of solutions. Finding the optimal solution often requires creativity on the part of the designer.

The United Kingdom has a national curriculum in design & technology to prepare students for creative design and technological innovation. A recent report by the UK Department for Education [16] lists the key features of the curriculum as

- **Design** – identify user needs and practical problems; devise possible solutions
- **Make** – choose a solution and select the tools and materials to create a product
- **Evaluate** – test, evaluate, and critique the product against a set of specifications
- **Technical Knowledge** – understand the scientific and engineering principles governing the product or system

Often design has been seen too narrowly in the context of subjects as Design & Technology Education or even in Craft Education. Our aim is to show that the competencies in this field can be applied in many areas of peoples' everyday life. In this context we see design-based approach as strategy for solving one of a very complex type of problems – design problems. Design problems are introduced by Jonassen (2000) [17] as problems where problem solvers have to act on goals to produce artifacts even if there is only a vague goal with few guiding constraints. It assumes the problem solver to structure work, to set multiple undefined criteria for the expected solution in a context of a particular situation. Thus, it is a very ill-structured problem but very common in real life.

Comparing design to digital literacy reveals the strongest similarity in terms of making and creating. Hands-on, playful design work appeals to young people and can motivate increased enthusiasm and engagement for learning science [18, 19]. However, a criticism of design is that students can frequently use a trial-and-error strategy to solve a design problem and thereby avoid learning underlying science and mathematics principles that are actually responsible for the working solution [20]. Therefore, combining aspects of design and inquiry, such as in integrative STEM, offers potentially rewarding advantages while avoiding the potential disadvantages of either approach individually.

5 Integrative STEM

The importance of both inquiry and design for science education was recently made explicit in a new framework issued by the National Research Council in the United States [21]. It stated that

… learning about science and engineering involves integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design. (National Research Council, 2012, p. 11 [21])

Lewis (2006) [22] argued that inquiry and design are conceptual parallels based on the unescapable interdependencies between science and engineering; and that integration offers greater prospects for learning in addition to increasing interest in science careers. Sanders (2009) [8] suggested that an integrated curriculum that "purposefully combines technological design with scientific inquiry" will help technology education become more relevant to society.

An integrative STEM graduate education program at Virginia Tech has been specifically created to embed technology/engineering design approaches into teaching science and mathematics content [23]. The goal of the program is to educate teachers with methods for implementing integrative STEM teaching practices. However, teachers still encounter challenges in implementing integrative STEM in practice [20]. There is a need for examples to illustrate effective implementations of integrative STEM in practice. Furthermore, the relevance of digital literacy for today's students is of great importance and should be included as part of integrative STEM instruction.

6 Digital Literacy through Integrative STEM

The features of digital literacy overlap with both inquiry and design and therefore integrative STEM is a suitable framework to facilitate digital competences. Moreover, teaching aspects of digital literacy in mandatory science and mathematics classes at the K-12 level guarantees that learning digital competencies is available to all students.

In the integrative STEM context, digital literacy could be implemented using innovative digital technologies. Two modern digital platforms that we consider promising are robotics and 3-D computer software. These digital platforms have been used in design approaches to motivate enthusiasm and interest in technology. But we contend that they can also be beneficially adapted for teaching science and mathematics, and hence appropriate in an integrative STEM context.

6.1 Robotics

Educational robotics provides a tangible and interactive learning platform for engaging students. But typical robot activities are mostly design based rather than inquiry-based and therefore using robotics to explore STEM concepts has not yet reached its full potential [24]. However, implementing an integrative STEM approach including digital literacy appears possible.

Improving mathematics learning with robotics is one promising start. Mathematical principles can be taught and motivated with robotics activities in the context of computer programming. The control and behavior of robots occurs through digital software instructions that must be programmed into a robot. The process of formulating an algorithm and writing code to program a robot requires mathematical sophistication. An effective program requires utilizing mathematical operators and manipulating variables (skills directly related to learning algebra). Robotics offers an opportunity to make abstract math concepts concrete. Design activities with robots can engage and motivate student learning.

In terms of science education, robotics can provide a systems-level model for learning a science topic. A system in the natural sciences is studied by breaking into separate parts, studying the parts individually, and then studying the interactions between the parts to see how the system as a whole behaves. Likewise, robots represent systems since they separate into parts with different functions; e.g. sensors collect input data, microprocessors process data, and electro-mechanical parts respond to output data sent from the microprocessors. The systems analogy between robotics and science therefore allows for an integrative STEM approach. Building and testing a systems model of a science topic using robotic parts is a promising way to implement a digital literacy based integrative STEM activity.

The digital competency benefits of robotics can include developing skills in electro-mechanics and computational thinking. In addition, working together in teams to design, build, and test a robot helps students learn to manage a project and work collaboratively.

6.2 3-D Computer Software

The growing popularity of 3-D printing has opened up a discussion about the potential of 3-D technology to improve learning. A recent pilot project by the UK Department for Education [25] explored the prospects of 3-D printers to enrich STEM education and found that

Feedback from this exploratory project confirms that 3D printers have significant potential as a teaching resource and can have a positive impact on pupil engagement and learning if schools can master how to use the printers in an effective and meaningful way. (UK Department for Education, 2013b, p. 23 [25]).

Therefore 3-D technology has promise but requires examples showing how to adapt the design-based use of 3-D technology with scientific inquiry. Siiman and Pedaste (2013) [26] proposed new ways of applying 3-D computer software to fulfill the complementary aim of learning science. They note that the structure and function of objects in nature, as well as their scale and proportion, are crucial elements to understand in science. But many objects are not accessible to direct observation or convenient to explore with traditional methods. Siiman and Pedaste (2013) [26] demonstrated interactive activities with digital 3-D models to teach the basic scientific fundamentals of structure, function, scale, and proportion. Practice with three-dimensional skills is also beneficial to science education because longitudinal studies have shown that 3-D spatial ability correlates strongly to success and achievement in science [27].

With respect to learning mathematics, 3-D software shares intrinsic links to the subject of geometry and the study of three-dimensional shapes. However, the animation features of 3-D software also allow for visualizing the motion of objects and studying concepts such as rate of change, a basic concept in calculus. Thus the potential of 3-D software extends across a range of mathematical topics and affords a diversity of learning options.

Although technology educators have extensively used 3-D computer assisted design (CAD) software to design and manufacture products, CAD software tends to be narrowly focused drafting technical drawings in engineering. In contrast, Siiman and Pedaste (2013) [26] chose an open-source 3-D software package mainly used by professionals and hobbyists in the arts & entertainment industries, but adapted it for educational purposes. The prospect of creating visually stunning visuals with 3-D software or designing 3-D models to manufacture using a 3-D printer is likely to stimulate the interest of students. Thus 3-D computer software promises new ways to motivate learning in an integrative STEM model that includes digital literacy.

7 Conclusion

Digital literacy can be facilitated through alignment with integrative STEM so that all K-12 students have the opportunity to acquire digital competences. Integrative STEM is a new educational strategy that attempts to merge the best features of scientific inquiry and technological/engineering design. At present more empirical data is necessary to find the most effective implementations of integrative STEM, but the aims and principles of the strategy are supported by a number of recent documents by national governmental organizations across the globe. Including digital literacy within integrative STEM follows naturally from technology designed-based approaches, but requires additional considerations for implementation with scientific inquiry or mathematics learning. We proposed robotics and 3-D computer software as two examples of digital platforms for implementing integrative STEM. Future work necessitates empirical testing to identify the practical effect with teachers and students.

References

1. de Jong, T., van Joolingen, W., Giemza, A., Girault, I., Hoppe, U., Kindermann, J., Kluge, A., Lazonder, A., Vold, V., Weinberger, A., Weinbrenner, S., Wichmann, A., Anjewierden, A., Bodin, M., Bollen, L., d'Ham, C., Dolonen, J., Engler, J., Geraedts, C., Grosskreutz, H., Hovardas, T., Julien, R., Lechner, J., Ludvigsen, S., Matteman, Y., Meistadt, Ø., Næss, B., Ney, M., Pedaste, M., Perritano, A., Rinket, M., von Schlanbusch, H., Sarapuu, T., Schulz, F., Sikken, J., Slotta, J., Toussaint, J., Verkade, A., Wajeman, C., Wasson, B., Zacharia, Z., van der Zanden, M.: Learning by creating and exchanging objects: The SCY experience. British Journal of Educational Technology 41(6), 909–921 (2010)

2. de Jong, T., Weinberger, A., Girault, I., Kluge, A., Lazonder, A.W., Pedaste, M., Ludvigsen, S., Ney, M., Wasson, B., Wichmann, A., Geraedts, C., Giemza, A., Hovardas, A., Julien, R., van Joolingen, W.R., Lejeune, A., Manoli, C., Matteman, Y., Sarapuu, T., Verkade, A., Vold, V., Wanders, B., Zacharia, Z.C.: Using scenarios to design complex technology-enhanced learning environments. Educational Technology Research & Development 60(5), 883–901 (2012)
3. Pedaste, M., de Jong, T., Sarapuu, T., Piksööt, J., van Joolingen, W.R., Giemza, A.: Investigating ecosystems as a blended learning experience. Science 340(6140), 1537–1538 (2013)
4. Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henrikson, H., Hemmo, V.: Science education now: A renewed pedagogy for the future of Europe. European Commission: Directorate-General for Research, Brussels (2007)
5. Chang, C.-Y., Tsai, C.-C.: The interplay between different forms of CAI and students' preferences of learning environment in the secondary science class. Science Education 89(5), 707–724 (2005)
6. Chang, C., Hsiao, C., Barufaldi, J.-P.: Preferred-actual learning environment "spaces" and earth science outcomes in Taiwan. Learning Environment Spaces 90(3), 420–433 (2006)
7. Alberts, B.: Restoring science to science education. Issues in Science and Technology. A Publication of National Academy of Sciences, National Academy of Engineering, Institute of Medicine, University of Texas at Dallas (2009), `http://www.issues.org/25.4/alberts.html` (retrieved December 14, 2013)
8. Sanders, M.: STEM, STEM education, STEMmania. The Technology Teacher 68(4), 20–26 (2009)
9. European Union. Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning. Journal of the European Union, L394 (2006), `http://eur-lex.europa.eu/LexUriServ/site/en/oj/2006/l_394/l_39420061230en00100018.pdf` (retrieved)
10. Hobbs, R.: Empowering Learners with Digital and Media Literacy. Knowledge Quest 39(5), 12–17 (2011)
11. Alfieri, L., Brooks, P.J., Aldrich, N.J., Tenenbaum, H.R.: Does discovery-based instruction enhance learning? Journal of Educational Psychology 103, 1–18 (2011)
12. Furtak, E.M., Seidel, T., Iverson, H., Briggs, D.C.: Experimental and quasiexperimental studies of inquiry-based science teaching. Review of Educational Research 82, 300–329 (2012)
13. de Jong, T.: Computer simulations: Technological advances in inquiry learning. Science 312, 532–533 (2006)
14. Mäeots, M., Pedaste, M., Sarapuu, T.: Interactions between Inquiry Processes in a Web-Based Learning Environment. Paper presented at the Advanced Learning Technologies (ICALT), 2011 11th IEEE International Conference on Advanced Learning Technologies, Athens, USA (2011)
15. Brophy, S., Klein, S., Portsmore, M., Rogers, C.: Advancing engineering education in P-12 classrooms. Journal of Engineering Education 97(3), 369–387 (2008)
16. UK Department for Education. National curriculum in England: design and technology programmes of study (2013), `https://www.gov.uk/government/publications/national-curriculum-in-england-design-and-technology-programmes-of-study` (retrieved)
17. Jonassen, D.H.: Toward a design theory of problem solving. Educational Technology Research and Development 48, 63–85 (2000)

18. Cantrell, P., Pekcan, G., Itani, A., Velasquez-Bryant, N.: The effects of engineering modules on student learning in middle school science classrooms. Journal of Engineering Education 95(4), 301–309 (2006)
19. Cejka, E., Rogers, C., Portsmore, M.: Kindergarten robotics: Using robotics to motivate math, science, and engineering literacy in elementary school. International Journal of Engineering Education 22(4), 711–722 (2006)
20. Roehrig, G.H., Moore, T.J., Wang, H.H., Park, M.S.: Is Adding the E Enough? Investigating the Impact of K-12 Engineering Standards on the Implementation of STEM Integration. School Science and Mathematics 112(1), 31–44 (2012)
21. National Research Council. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. The National Academies Press, Washington, DC (2012)
22. Lewis, T.: Design and inquiry: Basis for an accommodation between science and technology education in the curriculum? Journal of Research in Science Teaching 43, 255–281 (2006)
23. Wells, J.G.: Integrative STEM education at Virginia Tech: Graduate preparation for tomorrow's leaders. Technology & Engineering Teacher 72(5), 28–34 (2013)
24. Altin, H., Pedaste, M.: Learning approaches to applying robotics in science education. Journal of Baltic Science Education 12(3), 365–377 (2013)
25. UK Department for Education. 3D printers in schools: uses in the curriculum (2013), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251439/3D_printers_in_schools.pdf (retreived)
26. Siiman, L.A., Pedaste, M.: Towards a pedagogy for using digital 3-D content in science education. In: 6th International Conference of Education, Research and Innovation (ICERI 2013), Seville, Spain, November 18-20, pp. 5992–5999 (2013)
27. Wai, J., Lubinski, D., Benbow, C.P.: Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance. Journal of Educational Psychology 101, 817–835 (2009)