How Technologies Motivate and Enhance Student Learning

H. Keers, *Institute of Earth Science, University of Bergen, Norway*
A. G. V. Salvanes, J-A. Grytnes, *Department of Biology, University of Bergen, Norway*
R. Waagbø, *NIFES/Department of Biology, University of Bergen, Norway*

ABSTRACT: The use of technology in university teaching is ubiquitous. Therefore, the classification of courses using technologies has received considerable attention. Motivated by a discussion of teaching in the natural sciences we present a natural classification consisting of 1. technology which is absolutely essential for learning because the technology itself is what is being taught (for example computer programming or the use of hardware/software in data acquisition and processing) and 2. technologies which are not essential for learning but that enhance the teaching and learning. In any given course these categories may or may not be combined thus resulting in four different types of courses. This categorization is illustrated using three different science courses. The classification is neutral and therefore not an indication of the relative importance of the four categories, but rather a clarification for use in university policy discussions and further research in the use of technology in higher education.

1 INTRODUCTION

Over the past 30 years the use of technology in higher education has been a topic of much debate and research. This has resulted in many books (e.g. Beetham and Sharpe (2013) and Selwyn (2017)), more than 70 different types of journal on education and technology (see e.g. http://educationaltechnology.net/educational-technology-journals-peer-reviewed/ for a listing of these journals), many thousands of articles, reports (e.g. OECD Pisa report (2015), NRC report (2002), NAE report (2017)) as well as many new university courses that use some type of technology. Moreover, the number of technologies used is both high and varied and includes older technologies such as computer programming and data acquisition as well as new technologies that use apps on mobile phones in field courses (e.g. Jeno et al., 2017) and Google-Earth.

Given the importance as well as the wide variety of technologies in higher education a categorization of these technology based teaching would be useful and for this purpose several have been developed. The most popular seems to be 'The Technological Pedagogical Content Knowledge Framework' TPACK (see e.g. Mishra and Koehler (2006) and Koehler et al. (2016)), which focuses on the overlap of three different domains: pedagogical knowledge, content knowledge and technological knowledge. Another categorization emphasizes, in addition to pedagogy and technology, the importance of social interaction Wang (2008). Wang (2008) moreover mentions several other types of categorization, including ASSURE (Analyse learners; State objectives; Select media and materials; Utilise media and materials; Require learner participation; Evaluate and revise) by Heinrich et al. (2001). In fact, the demand for this type of categorization is so high that even a categorization such as the Substitution Augmentation Modification Redefinition (SAMR) model (Puentedura, 2006), which has been criticized for not being based on research (Hamilton et al., 2016), has been used by policy makers and university administrators. Thus, several categorizations exist and it is not clear whether any of these is the best or whether perhaps the classification is course dependent.

An additional difficulty is that despite the large number of papers on the use of technology in education, and despite the various categorizations, there is little evidence that using a certain technology positively affect students' learning (OECD Pisa Report (2015)). Indeed Kirkwood and Price (2013a, 2013b, 2014) and Price and Kirkwood (2014) argue that it is in practice quite difficult to collect evidence that a certain technology does indeed enhances students' learning.

In this paper, we present a new and natural way to categorize the use of technology in higher education. Given the wide variety of topics in university education, we restrict our discussion to the natural sciences. However, many arguments probably also hold in other fields. In the next section, we briefly describe our new categorization and why it is natural. Then we illustrate the new classification using three case studies. The focus in this categorization is on biology and Earth sciences, as historically these fields were rather qualitative and descriptive, while they nowadays are very much technology driven. We then conclude with a discussion on how our categorization relates to students' learning, and how it is related to the TPACK categorization.

2 SCIENCE TEACHING AND TECHNOLOGY

The goal of university education, including science education, is to prepare the student for relevant work in either the public (university, government, publicly funded institutions) or private sector. In many of these jobs, not least the ones in research or development, the use of various, often advanced and specialized, types of technologies has become standard. University education therefore to a large extent focuses on familiarizing these students familiar with contemporary technologies and in particular how and why they are used. A natural categorization of science courses therefore distinguishes between courses in which the use of technology is essential, in that the technology is what is being taught, and those in which technology is not essential.

In physics and many adjacent fields, such as computational chemistry, physical and biological oceanography and solid Earth physics, forward modelling and inverse modelling have become standard. In forward modelling/simulation, computer programs are used to solve various types of (differential) equations to model certain physical phenomena. In inverse modelling, including parameter estimation, various types of data are processed and analysed to determine a wide variety of physical properties (see e.g. Aster et al., 2005) and to express, for example, biological phenomena and functions. In both forward and inverse modelling, the technology consists of both hardware and software. As an illustration of the wide use of computer programming alone one can point to the more than 1800 books on programming in Matlab (a programming language used especially by the scientific and engineering communities; see www.mathworks.com/support/books). In addition, many papers have been written on various aspects of teaching in these areas (see e.g. Landau (2007), Maszovsky et al. (2012) and Psycharis (2011)). Thus teaching in the natural sciences requires in a very natural way the use of many different types of technology, as the technology is what is being taught.

Sciences that have traditionally been more qualitative (such as biology and geology) have, in recent years, also become more quantitative and use many different types of technology. For example, in geology the use of ArcGIS and Google Earth (e.g. Lisle (2006), Ratinen and Keinonen (2011)), to study for example, fluvial systems on a large scale, has become standard in research and therefore, in order to prepare students for research, these technologies have also become part of university classes in geology. In these more descriptive research areas the distinction between forward modelling and inverse modelling makes less sense, if only because often mathematical equations are (still) lacking. However, the use of some kind of technology in the courses is also in this case essential as the technology is part of what is being taught. Thus in the sciences there is a large category of classes in which technology is an essential and indispensable part of the teaching.

One can therefore in general differentiate between courses in which technology are needed for the teaching, as the technology is part of the curriculum, and in which case teaching without technology does not make sense, and other courses in which this technology is not part of the curriculum. We call these two categories I and II respectively. Obviously there are many ways in which all kinds of technologies can be used to enhance either of these categories. This results in another categorization of classes, which distinguishes whether these non-essential categories are used in teaching or not. These might are called categories A and B. It should be emphasized that non-essential technology in this context means that the technology is not what is being taught, but that, in contrast, the technology is used to enhance teaching and learning. Obviously, any class consists of a combination of the two different categories (I/II and A/B) and we thus we have four different types of classes (see Table 1). In order to illustrate this in more detail in the next section we explicitly discuss three of these four different types of classes. The first class falls in category IA (technology is needed and other non-essential technology is used to enhance the learning). The second class falls in category IB (technology is needed, but no non-essential technology is used). The third class falls in category IIA (technology is not strictly needed, but non-essential technology is used). A fourth class, which would fall in category IIB as it does not use any type of technology, is not discussed in detail here but could for example be a class in theoretical physics or a biological taxonomy class. It should be emphasized that this categorization is not a ranking of the classes. In particular, it does not indicate whether, for example, a category IA class is more important than a category IIB class, or the other way around.

	I: Technology essential	II: Technology not essential
A: Non-essential technology used (i.e. technology that enhances the learning)	IA	IIA
B: Non-essential technology not used	IB	IIB

Table 1. Categorization of the use of technology in university courses; see the text for a detailed explanation.

3 CASE STUDIES

3.1 Case study 1: Marine Ecological Field Methods; integrating IT with advanced technology

At the Department of Biology at the University of Bergen, we run a field course for master students in Marine Science onboard ocean going Research Vessels. Here students learn to plan and conduct marine ecological studies using essential and advanced technologies applied on a common biological phenomenon: Diurnal Vertical Migration (DVM). Hydroacoustics demonstrates which depths organisms aggregates. Large trawls mounted with a depth sensor, a MultiSampler & 3 bags sample these aggregations to identify and quantify species of fish, jellyfish, krill and shrimps from specific depth ranges. Hauls using Multinets with 5 bags that each open and close at chosen depths provide the density distribution of zooplankton, and flowmeters measure the volume of water sieved by each net. Depth profiles of environmental parameters, such as temperature, salinity, light and oxygen are measured using sensors and optics (see Figure 1). Remotely Operated Vehicles (ROVs) observe animals alive in their natural environments. Students sort and measure all collections and organize the data on spreadsheets. Back on land, it is essential that they learn to use statistical software R (R project core team, 2016) to explore and interpret the data. Their field study concludes with an individual field report (exam) where students demonstrate achieved knowledge and analytical skills.

All advanced technologies used to sample the marine environment may overwhelm students. To enhance learning of methods, all operations onboard are video recorded. Back on land, student groups utilize video material to produce short video-tutorials on key concepts of the various marine sampling methodologies (http://teach2learn.b.uib.no/category/biocruise/bio325-ocean-science/). This stimulates creativity and develops collaborative, communicative and pedagogical skills. The production is in collaboration with the TE2LE (bioCEED) project.

In this case study, some of the technology (sensors, acoustic equipment, trawl and net operations etc.) is indispensable for teaching the course. Another part of the technology, video tutorials, is used to enhance the students' learning. Consequently, this course may be categorized as IA.

3.2 Case Study 2: Laboratory classes

This course deals with applications of technological equipment and data handling in nutritional science education in laboratory classes. Like many other research driven technologies food chemistry analysis develops rapidly, from basic analytical principles in biology and chemistry to highly advanced methods ("omics" platforms) that generate and process large data sets.

The present laboratory course in food chemistry at the Department of Biology, University of Bergen, takes the student out of the university learning environment and into an associated institution with accredited high-tech laboratories with routine analyses of nutrients (and toxicants). Examples of techniques include ICP-MS for element analysis and ultra-performance chromatography with different detection principles (UV light, flame ionization, thermal conductivity, fluorescence). The aims and learning outcomes of the laboratory course implies that the students learn applications of state-of-the-art advanced technologies in infrastructures and modern instruments that are in use in society and in a multitude of relevant research questions.

The accredited laboratories have strict rules in the daily routines and require responsible students in smaller laboratory groups (<10 students) that prepare their activity in very detail before they enter the laboratories and take the instruments in use. The benefit for the student is that the learning facilities have qualified persons to lead the laboratory sessions and learn the students their responsibility for the equipment, chemicals, and not at least cleanup of the facilities. They learn that the advanced equipment is only one part of the analysis, besides strict routines on sample preparation and clean-up steps, as well as handling of data by use of instrumental specific software. They report and discuss the processed data in reports that are part of the assessment.

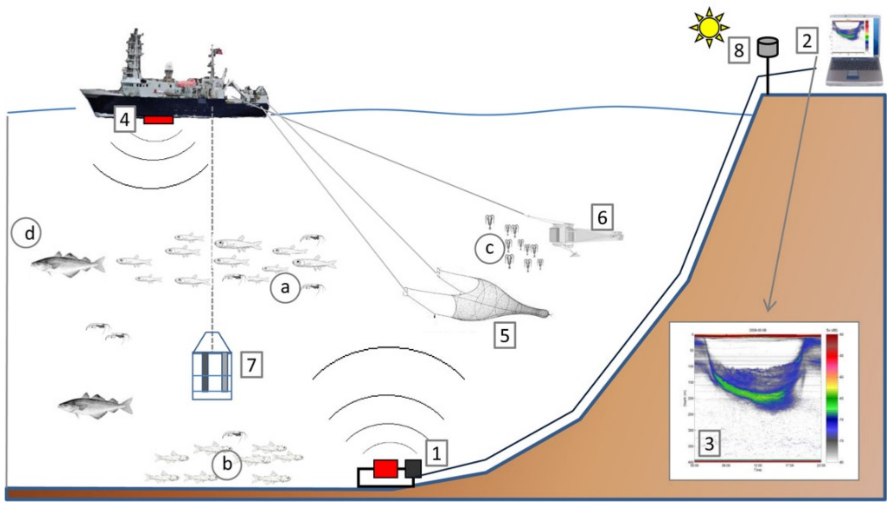

Figure 1. Various types of equipment onboard an ocean going research vessel used to sample the marine environment in coastal and fjord areas. 1) An upward facing EK60 38kHz transducer located on the bottom of the fjord connected to a (2) laptop on land, where detection of organisms occur in real-time (3). Data from the hull mounted echosounder is used to visualize acoustic targets / scattering layers at different depths. 5) A pelagic trawl combined with a MultiSampler verifies species composition of acoustic signals / targets (a, b, and d), 6) a plankton sampler to collect depth-stratified plankton samples (c), 7) CTDO to recorded environmental data throughout the water column, and 8) a light sensor measured radiation every 15 minutes. Large predatory fish (d) can be captured by rod and reel. Figure made by Arved Staby for Salvanes et al. (in press).

The course is very popular among students late in their bachelor study, probably related to the practical profile and preparing them for their laboratory work in their coming master study. Surprisingly, the students react positively to the strict demands in the laboratory classes, even though this means more work and longer working days. The discussion of the self-produced results should include a societal component, like the relevance of nutrient analysis in feed, food and food products for planning and confirming the nutrient composition in human foods (appearing in food composition databases like www.sjomatdata.nifes.no), fish feeds and biological modelling. Many of the analyses learned in the course are of relevance for the public debate, which also give the students possibilities to have a qualified meaning. This course, where technology is needed, but no non-essential technology

3.3 Case Study 3: Fieldwork on Land

At the department of Biology, University of Bergen, we run a field course over 3 weeks for bachelor students in biology as a start of their second year as bachelor students. One of the main topics in this field course is identification of species. Traditionally, different floras and faunas with professional keys are used to teach the students how to identify species. These keys consist of specific questions referring to different morphological features of the specimen we want to identify, and the students have to go through the questions in a predetermined way. These keys are also commonly made for professionals and assume that the students are familiar with the professional terms. To increase the motivation for learning to identify species we developed ArtsApp, a smartphone application, for use in the course. ArtsApp uses the same concepts as in the traditional keys but with some additional advantages. First, it is on a platform that most students are familiar with (their smartphones). Second, it allows a larger degree of freedom for the students, by allowing them to choose the questions they find easiest and at the same time reduces the number of potential species. Third, they get immediate feedback in form of how many species are left after they have made a choice. A study on how the students perceive the app has confirmed that the students experienced a higher degree of self-determination and through that a higher motivation for learning species (Jeno et al., 2015). The technology used in this course is not part of the curriculum and is only used to enhance learning and therefore falls in our category IIA

4 DISCUSSION AND CONCLUSIONS

We have presented an alternative categorization for the use of technology in university science education. This categorization makes a clear distinction between courses in which technology is an essential part of the curriculum (i.e. the technology is what is taught and it would not make sense to teach the course without this technology) and courses in which technology is not essential. Furthermore, as there is an ever-increasing use of non-essential technology in education we distinguish between courses in which this latter type of technology is used and which it is not. Thus, we arrive at 4 different types of categories as summarized in table 1. This categorization is natural, as it is driven by the needs in science and should have a profound impact on how technology is and should be used in the class.

Specifically in the natural sciences the distinction between the use of essential technology (software and/or hardware) and non-essential technology should be helpful. Many courses that have been taught at least since the 1980s use technology that is essential. This is to a large extent to the need to solve complicated (differential) equations for modelling/simulation and also for the processing of data for parameter estimation and inversion, often using various types of optimization algorithms. More recently, in geology and biology, the use of essential technology has increased considerably. This is illustrated by three case studies: one course in which essential technology and non-essential technology are used, one course in which only essential technology is used and one course in which only non-essential technology is used.

The categorization presented is not a judgement on whether or not one type of category is more important than the other. It should however help discussions about whether or not to put resources into the use of technology in higher education, assist in university policy decisions on whether or not to implement certain technologies and clarify issues on technology in higher education for the field of educational research. Other classifications such as TPACK, which describes 'knowledge needed for a teacher for effective technology integration' (Koehler et al., 2014), can still be used but in general seem more useful when studying the non-essential technologies for enhancement in teaching and learning than the essential technologies. In particular, if technology is essential then educational research should assume this technology as given and focus on the best way students can learn this particular technology, using, for example, a particular active learning technique (e.g. Freeman et al. (2014) and Keers et al. (2014)).

In this paper, the focus has been on university science education. However, the categorization presented is also applicable in other fields including mathematics (for example Singular (singular.mathematik.uni-kl.de)), computer science, finance, economics and econometrics. Moreover, the categorization can also be used in high-school education systems. As in universities, also there it should help in discussions on optimal use of resource education in relation to teaching with or without technology.

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REFERENCES

Aster, R. C., B. Borchers, C. H. Thurber (2005). Parameter Estimation and Inverse Problems, Elsevier.

Beetham, H. and Sharpe, R. (editors) (2013). Rethinking Pedagogy for a Digital Age, Routledge, New York.

Freeman, S. and others (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences 111**:** 8410-8415.

Hamilton, E. R., Rosenberg, J. M., Akcaoglu, M. (2016). The Substitution Augmentation Modification Redefinition (SAMR) Model: A Critical Review and Suggestions for its Use, *Technology Trends*, 60, 433-441.

Heinrich, R., Molenda, M., Russell, J. D. and Smaldino, S. E. (2001). Instructional media and technologies for learning (7th edition), Englewood Cliffs, NJ, Prentice Hall.

Jeno, L. M., Grytnes, J.-A. and Vandvik, V. (2015). The effect of a mobile-application tool on biology students' motivation and achievement in species identification: A Self-Determination Theory perspective. *Computers and Education*, 107, 1-12

Keers, H, Rondenay, S, Yael, H, Nordmo, I. (2014). Resources for computational geophysics courses. *EOS: Transactions* Vol. 95, No 7, 335-336.

Kirkwood, A., Price, L. (2013). Examining some assumptions and limitations of research on the effects of emerging technologies for teaching and learning in higher education, *British Journal of Educational Technology,* 44(4), 536-543.

Kirkwood, A., Price, L. (2013). Missing: evidence of a scholarly approach to teaching and learning with technology in higher education, *Teaching in Higher Education*, 18(3), 327-337.

Kirkwood, A., Price, L. (2014). Technology-enhanced learning and teaching in higher education: what is 'enhanced' and how do we know? A critical literature review. *Learning, Media and Technology*, 39(1), 6–36.

Koehler, M. J., Mishra, P., Kereluik, K., Shin T. S., Graham, C. R. (2014). The Technological Pedagogical Content Knowledge Framework, in J. M. Specter et al. (eds.), *Handbook of Research on Educational Communications and Technology*, 101-111, Springer Science+Business Media New York, 2014.

Landau, R. H. (2007). Computational Physics Education: why, what and how, *Computer Physics Communications*, 177, 2007, 191-194.

Lisle, R. J. (2006). Google Earth: a new geological resource, *Geology Today*, 22, 29-32.

Maszowsky, D, Halioua, G., Adler, J, (2012). The Role of Projects in (Computational) Physics Education, *Physics Procedia*, 34, 1-5.

Mishra, P., Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge, *Teachers College Record*, 108, 1017-1054.

OECD (2015). *Students, Computers and Learning: Making the Connection,* PISA, OECD Publishing. *http://dx.doi.org/10.1787/9789264239555-en*

National Academy of Engineering (2017), Engineering Technology Education in the United States.

National Research Council (2002). Improving Learning with Information Technology.

Price, L. and Kirkwood, A. (2014). Using technology for teaching and learning in higher education: a critical review of the role of evidence in informing practice, *Higher Education Research and Development*, 33, 549-564.

Puentedura, R. (2006), Transformation, technology and Education. Retrieved from http://hippasus.com/resources/tte.

Psycharis, S. (2011). The computational experiment and its effects on approach to learning and beliefs on physics, *Computers and Education*, 56, 547-555.

Ratinen, I, and T. Keinonen (2011). Student-teachers' use of Google Earth in problem-based geology learning, *International Research in Geographical and Environmental Education*, 20, 345-358.

R Core Team (2016). R: A Language and Environment for Statistical Computing, https://www.Rproject.
org/

Salvanes A. G. V.**,** Devine J., Jensen K. H., Hestetun J. T., Sjøtun K., Glenner H., (in press). *Marine Ecological Field Methods. A Guide for Marine Biologists and Fisheries Scientists*. Wiley Blackwell

Selwyn, N. (2017). Education and Technology – Key Issues and Debate, Bloomsbury Press, London.

Wang, Q. (2008). A Generic Model for Guiding the Integration of ICT into Teaching and Learning, *Innovations in Education and Teaching International*, 45, 4, 411-419.