Education, Training, Competencies, Curricula and Technology

Full STEAM Ahead

J. Michael Spector

Abstract Educational goals are relatively stable with shifting emphases among such large aims as developing critical thinkers, effective problem-solvers, productive workers, responsible citizens and lifelong learners. Nations strive to develop and maintain thriving economies with opportunities for citizens. Companies focus on gaining a secure place in the market and increasing profits and returns on investments. Technologies, however, are changing rapidly and, as a result, changing how people work and interact in nearly every sector, including education. One consequence of this convergence of situations is a tension in training and education. On one hand, new technologies provide the ability to support highly personalized and learner-centered education. On the other hand, there is pressure to focus on knowledge and skill development in the areas of science, technology, engineering and mathematics, in large part to serve economic growth and expansion in a highly competitive world. This chapter focuses on technology-enhanced learning informed by the arts and humanities as a way to balance tensions between individual and societal interests.

Keywords Competency-based instruction · Curriculum design · Educational goals · Training design · Technology integration

Introduction

The history of education dates back thousands of years. In one form or another, education has generally involved training people how to succeed in life. Such training might have emphasized the development of hunting and fishing skills or knowledge about soils and plants in earlier times. In modern times, educational goals are more often associated with the development of problem solving and critical thinking skills. In addition, education aims at the development of responsible citizens and lifelong learners (Spector, Johnson, & Young, 2014).

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Broad educational goals can be deconstructed into things that can be learned and supported with instruction and performance support. These can be further categorized in terms of a particular task domain or cluster of related knowledge and skill sets, which might then become parts of a curriculum. For example, a critical thinking goal might be decomposed into sub-goals, such as analyzing arguments, identifying assumptions, evaluating evidence, formulating implications, and so on (Fisher & Scriven, 1997). At a certain level of decomposition in many cases, it is possible to specify measures and assessments that can be associated with competent or masterful performance. This line of thinking from goals to clustered objectives with associated assessments is the basis of competency-based curricula that one finds implemented in many training situations. Such thinking has been more or less loosely used to structure primary, secondary and tertiary educational curricula in many subject areas as well.

There is an increasing emphasis on competence-based curricula as societies strive to increase the ability to create and sustain globally competitive economies (Rust, Portnoi, & Bagley, 2010; see also http://tencompetence-project.bolton.ac.uk/). The pressure to create a workforce educated to be competitive in the 21st century has led to an emphasis on STEM (science, technology, engineering, and mathematics) education. While new technologies make it possible to design, develop and deploy powerful STEM learning environments, many of these technologies can also support learning that is not tightly linked to competence development, such as open-ended, informal, technology-enhanced environments such as San Francisco's Exploratorium (see http://www.exploratorium.edu/).

As it happens, education in the liberal arts and humanities has not been easily or readily adapted to a competency-based model. In many liberal arts subjects, emphasis is on creativity and personal expressions which are not so easily measured or assessed. As it happens, there is evidence to support the notion that a liberal arts education with a rich infusion of the humanities can prepare a person for success in many occupations requiring creative and flexible thinking (Ferrall, 2011). In this chapter, a competency-based, technology-enhanced framework that is appropriate for STEAM (science, technology, engineering, arts, and mathematics) is developed, along with a discussion of associated issues and controversies. An elaboration of the framework in the domain of advanced learning technologies is then presented. The chapter concludes with implications for further research and development.

STEAM is a movement championed by the Rhode Island School of Design to integrate art and design into STEM curricula (see http://stemtosteam.org/). This effort has been adopted as a central focus of the National Technology Leadership Coalition (NTLC; see http://www.ntlcoalition.org/) and its 11 member associations and journal editors who meet annually for a National Technology Leadership Summit (NTLS; see http://www.ntls.info/index.htm). The research in terms of impact on learning for STEAM curricula is basically qualitative (e.g., case studies) as the effort is relatively young without large-scale empirical studies. However, one indicator of the impact of STEAM can be seen in many transmedia books that have emerged from NTLS, the University of Virginia, MIT and other institutions around the world (Bernardo, 2011; Phillips, 2012; Pratten, 2011). A transmedia book is essential a story told using digital technologies as an integral part of the story. Often there are activities for learners aimed at developing their critical thinking and problem solving skills. As a consequence, excellent examples of STEAM can be found in those transmedia books now available that illustrate how art, design, storytelling, and collaborative problem solving activities can be effectively integrated into a STEM curriculum.

Definitions and Rationale

In the course of developing a framework for integrating the arts and humanities into curricula for STEM disciplines, it is necessary to define key terms and provide a rationale. First, the following definitions inform this framework:

- Competence: an observable set of related skills, knowledge and attitudes that enable a person to effectively and consistently perform a task or job or achieve a desired outcome.
- Education: systematic efforts to develop critical thinkers (those who think critically and engage in higher order reasoning), effective problem solvers, productive workers, responsible citizens and lifelong learners; encompasses both formal and informal learning as well as apprenticeship, training and professional development.
- STEM: academic and professional disciplines associated with science, technology, engineering and mathematics; typically conceived of separately with sub-disciplines, although new pedagogical approaches encourage cross-disciplinary learning in areas.
- STEAM: the inclusion of the liberal arts and humanities in STEM education; some STEAM conceptions simply use the 'A' to indicate a fifth discipline area—namely, arts and humanities, with sub-disciplines as have historically existed for STEM areas; however, an alternative conception is to integrate liberal arts and humanities into STEM education as an expansion of an expanded cross-disciplinary approach being advocated for STEM education; some refer to this approach as *trans-disciplinary* and it is the approach advocated in this chapter (Nicolescu, 2008; Spector & Anderson, 2000; see also http://www.steamedu.com/ and http://stemtosteam.org/).

The rationale for integrating arts and humanities into and throughout STEM disciplines is multi-dimensional. One dimension concerns career progression. As has been demonstrated by the International Board of Standards for Training, Performance and Instruction (***ibstpi***) and many other organizations, advancement within a career area is highly correlated with communication skills, typically developed in courses offered within a liberal arts college (e.g., composition, debating, rhetoric, technical writing, etc.) or a business college (e.g., advertisement, leadership, persuasion, etc.). Communication skills are part and parcel of most jobs in the information age, but they are rarely emphasized in college courses in a STEM area. Those who can speak clearly naturally migrate to leadership and management positions.

I recall from my own experience with formal preparation in philosophy that when computers became commonplace in the workplace and in universities that new programs had to be developed for computer science teachers and those who would be working with computers after graduation. As there was a shortage of college faculty to teach computer science, initially mathematicians and engineers were recruited and cross-trained, but that effort did not meet the demand, so musicians and philosophers were then recruited and cross-trained, in part because those professionals also had experience with formal systems and symbolic notation. In short, there is historical evidence that preparation in the liberal arts and humanities can serve some people well in professional STEM areas.

Another dimension concerns ethics and values, which are normally taught in a philosophy department and which are not very popular with students majoring in STEM areas. However, many professional organizations have ethical standards that apply to everyone in that organization. While many do not regard professional ethics as a high priority personally, their professional associations do place emphasis on ethics. Evidence of this exists in the many large-scale surveys of professionals by the International Board of Standards for Training, Performance and Instruction (***ibstpi***; see www.ibstpi.org). That board establishes competencies and professional standards in a number of areas, and does so based on what practicing professionals regard as critical skills. When asked about the criticality of ethical practice in performing their various tasks, the respondents rank ethical competence as not critical. The Board has chosen in the case of ethics to base its standards on the Board's own view as opposed to the survey data; thankfully, that Board emphasizes ethics and recognizes the role of values in job performance.

In the 21st century with an explosion of information on the Internet, the responsibilities for respecting individual privacy and intellectual property rights is of increasing significance. It is all too easy to violate such rights, and the consequences can be personally and professionally devastating. There are recent examples in the area of ship, airplane and vehicular accidents that illustrate how poorly designed products as well as poorly designed training can result in the loss of life. Currently, the treatment of ethics and values in many STEM courses preparing those who develop complex systems and train professionals using those systems is minimal or non-existent. However, such issues are frequently discussed in philosophy and sociology courses, and relevant lessons could be usefully integrated into STEM courses.

Perhaps the strongest argument for integrating the liberal arts and humanities into STEM education is to emphasize the development of abilities associated with esthetics, innovation, and creativity (see the elaboration of a sample curriculum below). There are multiple strands to such an argument. First, many of the things associated with STEM careers involved the creation of products. Often, the success of a new product involves non-technical aspects of that product—notably, its esthetic appeal to targeted users. Some experience and familiarity with the design arts, can add significantly to the creation of various products that engineers and technologists develop.

Additionally, there is clearly value in having a sense of history. Understanding the past, including situations and developments that might be directly relevant to the present as well as those that might appear quite different, provides a basis for thinking about alternatives. For example, the success in war of a small army over a larger one might be understood in terms of a particular technology, and that understanding could lead to an innovative application of a derivative of that technology to serve a peacetime engineering need. While it is not well understood how discoveries occur, there does seem to be value in a liberal arts education in terms of creativity and innovation (Chopp, Frost, & Weiss, 2014; Jobs, 2013).

Finally, to create roughly equal emphasis on the common educational goals mentioned earlier and advocated by so many educators, it is essential to include some emphasis on developing an understanding of individuals, groups, cultures, nations, and such enterprises as design and public service (Dewey, 1916; see also http://www.aacu.org/leap/what_is_liberal_education.cfm).

A Competency Framework for STEAM

Based on the argument that a balanced STEM curriculum can be designed to integrate the liberal arts and the humanities, a preliminary and provisional framework for doing so is presented in this section. First, it should be noted that there is an active effort to integrate various STEM disciplines and subjects in curricula at different levels, especially in the USA. For example, the recently updated standards for teaching high school mathematics in Georgia dropped traditional courses dedicated to geometry, algebra, statistics and trigonometry in favor of integrated mathematics courses that covered related mathematical topics. In Mathematics I, algebra geometry and statistics are woven together in one course (for an elaboration see https://www.georgiastandards.org/Standards/Pages/BrowseStandards/MathStandards9-12.aspx). The Next Generation Science Standards (NGS) promoted by the National Research Council in the USA (see http://www.nextgenscience.org/). The NGS standards are a systematic effort to integrate science, technology, mathematics and engineering at the level of specific standards to be taught in various courses in K-12 settings in the USA. An example of a middle school standard in the area of forces and interaction is 3-PS2-3, which says that students who meet this standard will be able to ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other. For each NGS standard, a clarification statement is provided along with relevant science and engineering practices, core ideas and crosscutting concepts. This ambitious program to reform STEM education in public education is meeting resistance from teachers who have the task of supporting new standards. Nonetheless, there is widespread recognition that teaching separate subjects divorced from practical problems and real world practice is not meeting the needs of the 21st century.

Based on the assumption that industrial/manufacturing age curricula will eventually give way to dramatic curricular reformulations that are more interdisciplinary, integrative and holistic in nature, a provisional framework for such a STEAM curriculum reformation is presented next. First, it is worth noting developmental differences in a number of dimensions (see Fig. 1).

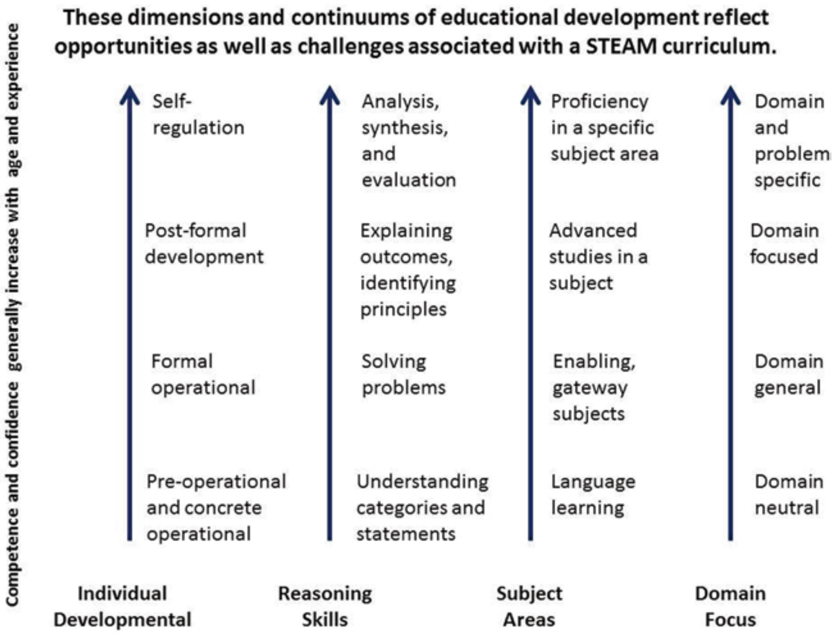

Fig. 1 Developmental dimensions

One way to elaborate a curriculum for a STEM subject involving systems (e.g., astronomy, biology, computer systems, ecology, engineering, etc.), especially for the middle parts of the developmental dimensions in Fig. 1, is in terms of graduated complexity (Milrad, Spector, & Davidsen, 2003). In terms of learner development, the progression would be from problem orientation (becoming familiar with representative problems and their dimensions) to inquiry exploration (engaging in hypothesis formulation and simple experimentation) and then to policy development (formulating decision making rules and guides appropriate for further inquiry and investigation). A holistic and systematic view would be supported throughout the curriculum. Specific challenges for learners (not unlike the challenges associated with NGS) could be sequenced from simpler to more complex as follows: (a) challenge learners to characterize the standard behavior of the complex system or document how system components changes over time; (b) challenge learners to identify key variables that affect the system; (c) challenge learners to explain how and why the system appears to change as it does, including those aspects of the system that might be amenable to control; (d) challenge learners to reflect and represent the dynamic aspects of a system in the form of white papers, decision guides, images, and dynamic models; (e) challenge learners to encapsulate a system in the form of a model or simulation including provisions for interaction and hypothesis testing; and (f) challenge learners to refine the model based on the results of hypothesis testing and the analysis and synthesis of related findings.

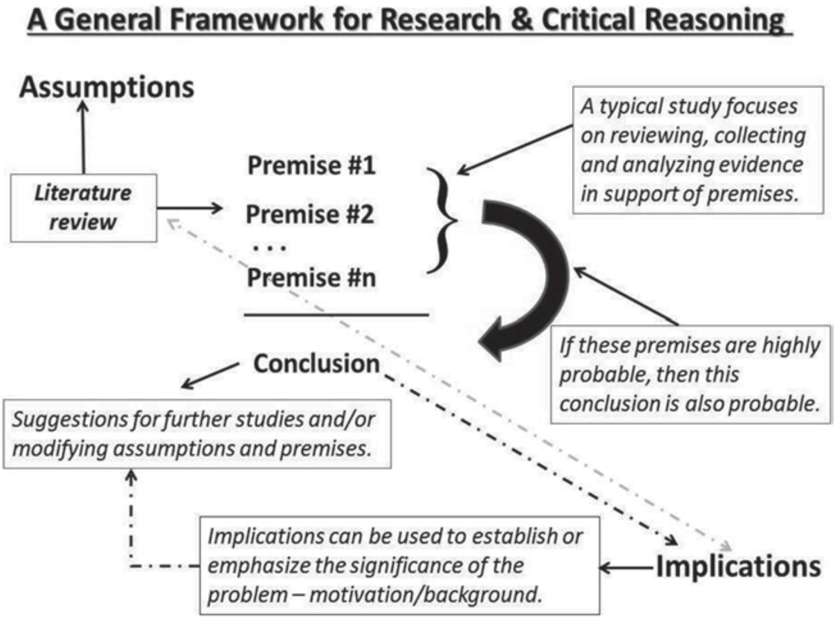

Fig. 2 Argumentation skills

Such a curriculum progression helps a learner develop increasingly sophisticated reasoning skills and includes skills that are typically developed outside a particular subject area focus (e.g., argumentation skills, mathematical modeling skills, visual representation skills, writing skills, etc.). Another way to frame a STEAM curriculum is with respect to a specific set of reasoning skills, such as argumentation. Figure 2 presents a framework focused specifically on the nature of argumentation skills, which might be associated with various parts of the dimensions in Fig. 1, depending on which argumentation aspects are emphasized.

Figure 2 depicts the general structure of an argument as consisting of some statements (premises) proposed as evidence or support for another statement (the conclusion). As it happens, this framework is appropriately applied to research as well as the development of critical reasoning skills. In a curriculum progression, early language training is typically focused on understanding statements. Gradually, comprehension is extended to paragraphs that might have a topical sentence or claim being supported. At that level of language developed, a curriculum informed by logic might challenge learners to distinguish the statements offered as evidence from those offered as the main point. A higher level of reasoning might then challenge learners to determine type of support being offered for the conclusion—probabilistic or certain (as in a mathematical proof). Then a learner could be challenged to examine additional literature to find support for the premises or conflicting evidence suggesting that the premises are not as strong as represented. Having learners identify unstated assumptions and the implications of a conclusion are again representative of higher order reasoning skills. In other words, applying lessons learned in a logic sequence typically taught in a philosophy curriculum could easily be infused throughout a STEM curriculum. Arguably, logic should be taught at the secondary level prior to college, although that is not standard practice in the USA.

An Elaboration for Advanced Learning Technology (ALT)

An example of a curriculum that integrates arts and humanities into a technology domain is one developed by the IEEE (Institute for Electrical and Electronic Engineers) Technical Committee on Advanced Learning Technologies (ALT) as part of a 3-year project ending in 2010 (Hartley, Kinshuk, Koper, Okamoto, & Spector, 2010). The domain was advanced learning technology. The IEEE Computer Society charged the committee with the task of developing a model curriculum for the preparation of the next generation of educational technologists that accounted for the dramatic changes occurring with regard to technology and scientific approaches to learning.

The five persons on the committee represented multiple disciplines (computer science, educational computing, educational psychology, educational technology, and philosophy) as well as having experience in academia as well as in business and governmental agencies in different countries and with a wide variety of institutions. The committee developed initial ideas based on their experience and preliminary research, and then held separate focus groups to expand those ideas. Eventually surveys of large groups of representative professional practitioners and academics were circulated and data analyzed and refined over a number of iterations and with the assistance of additional experts.

The initial perspective that resulted from the experience of two significant efforts—TEN-Competence in Europe (see http://tencompetence-project.bolton.ac.uk/) and the International Board of Standards for Training, Performance and Instruction (***ibstpi***), both of which had made extensive use of a competency approach with obvious success. A competence can be defined as a related set of skills, knowledge and attitudes that enable a person to consistently and successfully perform a particular task or job. Competences are by nature decomposable into sub-sets that lend themselves to measurements and assessments. As a result, competences are often associated with credentials and accreditation. Here is an example of an ***ibstpi*** competence for instructional designers (see www.ibstpi.org):

"Communicate effectively in visual, oral, and written form."

This competency statement is considered essential (required of all instructional designers) and elaborated in terms of ten performance indicators, with the following four considered essential:

a) Write and edit messages that are clear, concise, and grammatically correct.
b) Deliver presentations that effectively engage audiences and communicate clear messages.

c) Use active listening skills.
d) Solicit, accept, and provide constructive feedback.

Once a competence approach is adopted, the task is then to determine which competencies comprise a competency set and what the indicators of those competencies are. This is not a trivial undertaking and typically takes a significant period of time working with a large number of professionals in different contexts and locations.

The ALT committee took a year to develop the competency approach and about 2 years to determine a set of competencies appropriate for preparing advanced learning technologists. Working with the messy data collected, the committee arrived at 13 sets of related skills, knowledge and attitudes in terms of 13 topic areas:

1. Familiarity with advanced learning technologies;
2. Familiarity with human learning;
3. Prominent developments and how ALT has evolved;
4. Typologies and approaches for integrating technologies into learning;
5. User perspectives of learning and technology;
6. Learner perspectives of learning and technology;
7. Systems perspectives and systems thinking;
8. Social perspectives, including collaboration;
9. Design requirements, including needs assessment;
10. Design processes and the development lifecycle;
11. Instructional design, including alternative models;
12. Evaluation models and practices; and
13. Emerging issues in ALT.

These 13 topical areas were not necessarily intended to become separate courses; rather, they represent one way that the knowledge, skills and attitudes could be clustered into what might become units of instruction or parts of various courses. Here is how the committee elaborated topic area #2 in the above list (Hartley et al., 2010):

"The themes, issues and sub-competencies in this section include:

- Understanding and explaining human learning;
- Behaviourist and reinforcement views of human learning;
- Cognitive interpretations of learning;
- Socio-constructivist and emotive aspects of learning;
- Collaborative and cooperative learning;
- Distributed and distance learning;
- Instructional design perspectives, and
- Systems and Information processing approaches to learning." (p. 208)

This elaboration also demonstrates that the committee believes that a competent technologist should have a basic understanding of human psychology. Another way the committee looked at the data was in terms of competence domains; this perspective further highlights how the arts and humanities might be infused into a technology or engineering oriented curriculum. The committee identified these five domains that accounted for all of the competencies collected in the study:

- Knowledge competence—for example, the ability to synthesize research and theory pertaining to various aspects of advanced learning technologies.
- Process competence—for example, understanding how a particular system architecture creates some affordances as well as some limitations.
- Application competence—for example, the ability to transform a design specification into a prototype.
- Personal and social competence—for example, awareness of group dynamics and ethical issues.
- Innovative and creative competence—for example, understanding limitations and investigating alternative approaches.

The competence domains as well as the elaboration of the 13 topic areas lend themselves to implementation with a Four Component Instructional Design model (4C/ID; see van Merriënboer, 1997) or other instructional design framework that takes a holistic approach to learning and instruction (Spector, 2000).

These competence domains reflect a commitment to all of the educational goals mentioned at the beginning of this article—developing critical thinkers, effective problem solvers, productive workers, responsible citizens, and lifelong learners. Unlike many curricula, which target only one or two of the goals, the IEEE ALT curriculum addresses and integrates all of those goals. What does this demonstrate? This example can only suggest that it is possible to conceptualize a curriculum in a STEM area that integrates the arts and humanities, making it what could be considered a STEAM curriculum. It does not demonstrate the efficacy of such a curriculum, as that is a task yet to be undertaken.

Concluding Remarks

The message underlying the framework and example presented in this chapter is not simply that the arts and humanities should not be left out of a discussion about education in the 21st century. On the contrary, the message is that education in the arts and humanities should be part and parcel of education in every domain. There is empirical evidence that those with a strong background in the liberal arts are likely to be successful in attaining the education goals mentioned at the outset—namely, becoming critical thinkers, effective problem solvers, productive workers, responsible citizens and lifelong learners. Moreover, there is value in instilling the values associated with the arts and humanities into education—namely, the value of appreciating the complexities of life and the rich diversity of the world. Whether this is good for everyone at every level in an educational progression can be debated. The argument here is that a STEAM curriculum can inform both secondary and tertiary education, and help promote the value of inquiry in any discipline.

After all, inquiry involves a commitment to finding answers and explanations and an openness to alternative approaches and perspectives. As Perkins and Salomon (1989) have argued, a combination of domain-specific and general knowledge can function well in developing cognitive skills and expertise. Moreover, in becoming a critical thinker, effective problem solver, responsible citizen and life-long learner, there are also non-cognitive factors that can help or hinder those developments. Those non-cognitive factors are all often ignored in STEM courses. Addressing non-cognitive factors (e.g., cultural predispositions, deep-seated biases, emotional states, habits, motivation, etc.) can enhance learning outcomes. In addition, integrating aspects emphasized in the arts and humanities (argumentation, discourse analysis, esthetics, ethics, logic, etc.) can transform the current emphasis on STEM jobs and domain specific skills to inquiry-centered knowledge development appropriate for STEAM-based curricula (e.g., broad inquiry-based educational goals).

Acknowledgements The ideas expressed in this chapter are my own, as are any misconceptions and misleading comments. However, whatever stands the test of time, I owe to my parents, my siblings, my children, my teachers, my students and my friends from whom I have learned that becoming educated is learning to have questions, to pursue answers, and to admit limitations.

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