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Formative Assessment in Complex Problem-Solving Domains: The Emerging Role of Assessment Technologies

Kaushal Kumar Bhagat[1*] and J. Michael Spector[2]

[1]Smart Learning Institute, Beijing Normal University, China // [2]Department of Learning Technologies, University of North Texas, USA // kkntnu@hotmail.com // mike.spector@unt.edu

[*]Corresponding author

ABSTRACT

Much of the focus on learning technologies has been on structuring innovative learning experiences and on managing distance and hybrid learning environments. This article focuses on the use of technology as an important formative assessment and feedback tool. The rationale for this focus is based on prior research findings that suggest that timely and informative feedback promotes learning. The general purpose of this article is to promote a focus on formative assessment, especially with challenging problems so as to help develop critical thinking skills. This is not a meta-analysis although we encourage such studies so as to emphasis the role that formative assessment plays in supporting learning. Much of the prior research on formative assessment has not involved advanced digital technologies and very little of that research has focused on complex and challenging problem-solving tasks. We review prior work on the use of problem conceptualizations elicited during problem solving activities and on stealth assessments of learner choices and decisions in online activities. We present a conceptual framework based on prior research and theory for conducting formative assessments in real-time with regard to complex problem-solving tasks. We then present an elaboration of how formative assessment can be used to support learning a common intellectual skill involving a discrimination task and to develop an appropriate cognitive strategy for that kind of problem. We conclude with recommendations for further research on the use of technology in support of formative assessment.

Keywords

Cognitive strategies; Complex learning; Dynamic feedback; Formative assessment; Intellectual skills; Self-regulation

Introduction

There are three major findings from research on learning in the last 50 or more years (Narciss, 2008; Spector & Yuen, 2016): (a) time on task predicts learning outcomes, (b) formative feedback tends to improve learning, and (c) prior knowledge and experience influences learning. These three findings from learning research are related and have direct implications for formative assessment. First, however, we need to define the scope and purpose of formative assessment. Formative assessment is feedback provided to the learner during an instructional sequence or learning activity that is aimed at helping the learner succeed. Timely and informative feedback is essential for formative assessment to be effective, although the amount and timing of feedback should be appropriate for a particular learner. This is how prior learning and experience is related to formative assessment. More advanced learners require less support and may regard too much feedback as intrusive according to the research on cognitive apprenticeship (Collins, Brown, & Newman, 1987). In addition, learners who spend more time on a learning activity or task are likely to gain more understanding and competence, so formative feedback that encourages continued engagement is also likely to be more effective in support of learning (Spector & Park, in press).

In general, there is sufficient research on formative assessment to support learning simple tasks in well-structured domains with outcomes targeted at simple concepts and procedures. The explosion of new technologies makes such support ever more effective. What is less well understand is how best to support learning complex and ill-structured tasks and how best to use new technologies to support formative assessment in those situations. That gap is the focus of this contribution. The good news is that there are new techniques and findings emerging that should support progress in this important domain.

Formative assessment research

Research on formative assessment presents particular challenges, even though the benefits are widely acknowledged (Black & Wiliam, 1998; Dunn & Mulvonen, 2009; Fuchs & Fuchs, 1986). One challenge is to determine the influence of formative assessment on learning. If learning is defined as stable and persistent changes in what a person knows or can do (Spector & Yuen, 2016), then there is limited research as there are few studies that examine the persistence of learning and fading of knowledge and skills over time. A second challenge involves how and when formative assessments are provided. That is to say, while a particular feedback may be intended as constructive and encouraging, it may be perceived as discouraging or disheartening. In addition, a delayed feedback may not serve well to support continued engagement in a learning activity or instructional sequence. Finally, determining whether it was a formative assessment that led to an impact on learning rather than other factors is rarely explored in a controlled manner.

One reason for the lack of randomized controlled studies involving formative assessment is an ethical about potentially disadvantaging a group of learners not being provided a preferred form of feedback. One way to address that concern is through a within subject design using repeated and alternating treatments. Such a study should be sufficiently long with sufficient alterations to potentially observe differences due to different forms of feedback and should also involve measures before, during, after and long after the instructional sequence. In such a study there is the possibility that a learner will begin to generate a form of self-assessment that is similar to the kind of formative feedback expected to be most productive in terms of learning gains. Such a meta-cognitive learning outcome can be determined and is a desirable outcome aligned with the notion of self-regulated learning (Butler & Winne, 1995).

Complex learning

Some learning tasks and problems are more complex than others. Complexity can result from there being many interacting factors, from some of those interactions being non-linear with delayed effects, from changes in the problem situation changing while a solution approach is being formulated, and from lack of learner familiarity with the general nature of the problem or problem domain (Spector, 2015; van Merriënboer, 2012). Such problems and learning tasks often have multiple acceptable solution approaches and solutions, which presents a unique challenge for formative assessment. If supportive and potentially corrective feedback is not provided early in the process and in a meaningful manner, then a learner may develop misconceptions that are difficult to overcome later in a learning progression.

One fundamental theoretical foundation that has existed for some time is based on the notions of authentic learning introduced by Dewey (1938) and more recently elaborated in the form of situated learning (Lave & Wenger, 1991). These theoretical foundations strongly support two things. First, it is important to use meaningful and realistic problems to help develop complex problem-solving skills. Of course, prerequisite knowledge cannot be assumed, although the problem-based learning community argues that much prerequisite knowledge should be introduced while working on real problems (Barrows & Tamblyn, 1980). Complex problems that occur in so many domains are typically addressed by small groups of specialists. As a consequence, developing sufficient competence to be recognized as a contributing member of a problem-solving team in an important consideration (Lave & Wenger, 1991; Milrad, Spector, & Davidsen, 2003). In short, to develop complex problem—solving skills involves the development of competence and confidence. Previous attempts that emphasis summative assessments have tended to focus on the competence aspect of that developmental process. However, legitimate peripheral participation and more recent approaches place equal emphasis on the confidence aspect involved in critical thinking and complex learning (Kelller, 2010; Lave & Wenger, 1991; Milrad, Spector & Davidsen, 2003).

One approach, consistent with the foundations just reviewed, is to follow a path of graduated complexity and help the learner develop competence in a challenging problem domain (Milrad, Spector & Davidsen, 2003). Consistent with a graduated complexity approach is to use partially worked examples beginning with examples missing only a small part of an acceptable solution and then introduce examples with more and more parts missing eventually allowing a learner to develop an entire solution approach. In such cases, digital technologies can support such a process by knowing where a learner is within a learning progression path and introducing increasingly challenges examples to complete.

Yet another approach is to identify how experts typically think about that problem and use technology to encourage a learner to think more like an expert (Spector & Koszalka, 2004). This can be done by asking experts and learners to respond to four questions: (a) What key factors influence the problem situation? (b) How would you describe each of those factors? (c) What are the relationships among those factors? and (d) How would describe each of those relationships? Those responses can be put into the form of an annotated concept map and used as the basis for formative assessment.

These approaches are consistent with Dewey (1938), Lave and Wenger (1991), as well as with mainstream instructional design experts such as Gagné and Merrill (1990), Reigeluth (1999), and van Merriënboer (2012).

Gagné and Merrill (1990) proposed focusing on enterprises, which was called a whole task somewhat later by van Merriënboer (2012).Enterprises and whole tasks are authentic (representative of actual tasks) and consistent with the notion of problem-based learning (Barrows & Tamblyn, 1980). What is changing is the ability to provide real-time, meaningful feedback during problem solving using current and emerging technologies, which has been demonstrated by a few of the assessment technologies discussed in the next section.

Current assessment technologies and systems

Researchers have already accepted the importance of formative assessment in the teaching-learning process. In the 21st century, the availability and use of technological resources like computers, mobile devices, tablets, etc. are increasing rapidly in the school and higher education (Organisation for Economic Co-operation and Development (OECD), 2015). Now the question arises, "What kind of roles can technology play to support formative assessment?" For example, Bennett and Gitomer (2009) numerated some of the important benefits of using technology, which are: (a) more informative, technology can help to track the full record of the problem-solving process adapted by the learner; (b) more efficient, saves time for scoring and error free; and (c) cost-effective, saves the expenses over the human scoring process. Spector et al. (2016) also advocated the application of current available technologies for formative assessment purposes. In this section, we discussed some of the currently available systems for formative assessment. In addition, we presented some empirical evidence supporting the key role played by different technologies in formative assessment we discussed some of the currently available systems for formative assessment.

While the gap addressed herein concerns the lack of formative assessment in complex problem-solving domains, there have been recent improvements in technologies, which can and have addressed that gap, at least in research settings. These technologies, however, have yet to see large-scale implementation in instructional settings, so the gap previously discussed remains. However, the means to systematically address that gap are now possible due to emerging technologies. Recently, many digital assessment tools have been developed, which may provide support to FA. These tools include HIMATT (Pirnay-Dummer, Ifenthaler, & Spector, 2010), AKOVIA (Ifenthaler, 2014), AssiStudy (Rodrigues & Oliveira, 2014), iSMILE (Bhagat, Subheesh, Bhattacharya, & Chang, 2017), etc.

HIMATT (Highly Integrated Model Assessment Technology and Tools) is a comprehensive tool which combines the features of DEEP (Dynamic Enhanced Evaluation of Problem Solving), MITOCAR (Model Inspection Trace of Concepts and Relations), T-MITOCAR (Text-MITOCAR), and SMD Technology (Structure, Matching, Deep Structure). HIMATT has two platforms: HIMATT Research Engine, which conducts and analyses experiments and HIMATT Subject Environment, which assigns the experiments to the individuals dynamically. The application of HIMATT includes states and changes, analysis and comparisons.

The framework of AKOVIA (Automated Knowledge Visualization and Assessment) is based on HIMATT. It is applicable for the semantic analysis of natural language (e.g., discussion forums, essay writing) and graphical knowledge representations. Automated feedback is one of the key features of AKOVIA, which can help the learners to understand their writing and improve it accordingly in an effective way.

AssiStudy is based on Service-Oriented Architectures (SOA). It creates personalized training exams based on students' profile using question from the past exams stored in the repository. These training exams provide immediate feedback explaining the mistakes made by the students. This system used various Natural Language Processing (NLP) techniques to match reference answers (RA) with student answers (SA). After the training exams, teachers use students' performance information to develop evaluation exams. Three main types of exams can be created: enumeration, specific knowledge and essay. Evaluation exams are checked by both AssiStudy and the teacher. This system tracks the performance of each student in formative as well as summative assessment and provides detailed pattern analysis to the teachers.

Identification of Students' Misconceptions in Individualized Learning Environment (iSMILE) System is developed to provide feedbacks based on misconceptions in understanding a particular concept. This system is based on Model View Controller (MVC) architecture. Assessment procedure has two levels. Firstly, student needs to answer a root question. In the next step, a linked question is provided based on the answer for the root question to evaluate the deeper understanding of the concept. After finishing both levels, students are provided elaborated feedback about their misconceptions if they make any mistakes.

Hwang and Chang (2011) developed a Formative Assessment-Based Mobile Learning (FAML) system and evaluated on a local culture course learning. FAML used to provide only hints, when the students failed to find correct answers and motivated the learners to find the answers by their own. The results showed higher learning performance, learning attitude, and learning motivation by using FAML. In another study, an online game-based formative assessment named tic-tac-toe quiz for single-player (TRIS-Q-SP) was developed by Hooshyar et al. (2016). In addition, Hooshyar and colleagues (2016) integrated TRIS-Q-SP with an Intelligent Tutoring System (ITS) to teach computer programming. Three types of feedback (delayed feedback, knowledge result and elaborated feedback) were integrated within the system. The results revealed that TRIS-Q-SP improved experimental group's problem-solving skills, which resulted into better learning achievement. More importantly, immediate elaborated feedback was one of the reasons for better learning performance. Conejo, Garcia-Viñas, Gastón, and Barros (2016) employed a web-based assessment tool called *Siette* in a botany course for higher education. This system provided elaborated immediate feedback, which means the instant correct answer with detailed explanation for the wrong answers. They found that students who used *Siette*, performed better than the students who underwent traditional method for formative assessment. More interestingly, immediate feedback helped the students for better performance, which is not possible without the use of technology. Recently, Faber, Luyten, and Visscher (2017) examined the effects of a digital formative assessment tool, *Snappet* on students' mathematics achievement and motivation. This system also provides elaborated feedback about the errors made by the students and explanation for the correct answers. They also concluded that feedback contributed for the better performance and motivation of the students who used *Snappet.*

In addition, there is important research emerging with regard to the use of advanced technologies to support stealth assessment, which involves the use of log data in an online learning environment to determine areas in which a learner may be struggling and then help guide that learner to more productive outcomes (DiCerbo, Shute, & Kim, 2017; Shute & Moore, 2017). Moreover, the ability of digital technologies to collect data and present visualizations to help a learner make progress are also becoming more prominent in support of learning (Wang, Wu, Kinshuk, Chen, & Spector, 2013; Wu, Wang, Grotzer, Liu, & Johnson, 2016; Wu, Wang, Spector, & Yang, 2013; Yuan, Wang, Kushniruk, & Peng, 2016). Such visualizations often involve extensions of concept mapping techniques previously mentioned and address both content representations as well as feedback on student performance.

Looking to the future

Overall, research indicates that technology can support formative assessment to enhance learning performance, learning attitude, and learning motivation effectively across different disciplines. There is no doubt that technology can be used to support formative assessment, although technology has more often been used to provide access to and interaction with learning resources. Given the history of emphasis on formative assessment and the potential of new technologies to extend formative assessment into complex problem-solving domains, the potential for greater impact of formative assessment on the development of competence with regard to higher order learning is high. Promising technologies include stealth assessments, automated concept map based assessments, visualizations in support of formative assessment and self-regulation skills, and tools to promote networking and collaboration.

The conceptual framework we propose is to build on the following key notions:

- Continue to introduce real-world problems, however simplified, into curricula whenever possible;
- Build on the notions of graduated complexity (Milrad, Spector & Davidsen, 2003), enterprises (Gagné & Merrill, 1990), elaboration theory (Reigeluth, 1999), and whole tasks (van Merriënboer, 2012);
- Use annotated concept maps and causal influence diagrams as a means to elicit how someone is thinking about a complex problem;
- Compare progress towards expert-like thinking based on a series of problem conceptualizations.

Concluding remarks

In closing, it is our belief that formative assessment is an important albeit neglected task of educators. The primary job of a teacher is to help students succeed in their learning activities and educational pursuits. If one accepts that last remark, then one must continue to place emphasis on formative assessment and contribute to ongoing efforts to make effective use of new and emerging technologies in support of formative assessment, especially in complex problem-solving domains.

There are a number of ways to move forward with regard to a framework for supporting the development of complex problem-solving skills. These ways include the following:

- Develop repositories of representative complex problems in a variety of domains (this is being done with regard to a number of science learning tasks by the Smithsonian Institution – see https://ssec.si.edu/);
- Develop associated repositories of how experts think about those problems using annotated problem conceptualizations of the type found in DEEP and HIMATT (Pirnay-Dummer, Ifenthaler, & Spector, 2010; Spector & Koszalka, 2004);
- Develop a version of HIMATT that can be used in classroom and online course settings to provide dynamic, real-time feedback as a learner develops a conceptualization of the problem; and,
- Track and report the development of complex problem-solving skills because of using these technologies.

We have not reported new research in this short piece. Rather, we have been urging a particular perspective to support further research on the most promising technologies and learning approaches that have evolved in the last 50 years. What would be genuinely innovative and original would be to plan, implement, deploy on a large-scale version of the proposed approach and determine the impact on the development of critical thinking and complex problem-solving skills now being emphasized in so many places.

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