Towards a framework for games and simulations in STEM subject assessments.

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Abstract

Currently, providing games and simulations to address specific educational objectives in STEM subjects is a craft activity, requiring custom-built applications and hence making difficult-to-share and difficult-to-reuse solutions. To address this we propose a framework for the creation of Pedagogically Effective Games & Simulations (PEGS). The framework supports the construction and machine-processable expression of an educational intention which can be turned into a computer-deliverable serious game, simulation, or adaptive formative assessment with an element of pedagogical validity.

Understanding and the construction of knowledge comes through learners undertaking learning activities. We believe the most powerful learner activities in scientific, technological, engineering, and/or mathematical (STEM) subjects include serious games, simulations, and the building and running of models. This is because such learning activities inherently engage and motivate the learner through their characteristic combination of learning actions and consequential feedback. We also believe that undertaking formative assessments, exercises, and tests are equally powerful learner activities, particularly for developing motivation, and for contextual understanding of the subject domain and what the teacher, professional body, or certification authority 'really want'.

Currently, providing games and simulations to address specific educational objectives in STEM subjects is a craft activity, requiring custom-built applications and hence difficult-to-share and difficult-to-reuse solutions whose effectiveness is highly dependent upon the personal skills of specialist developers (Jantke, 2006; Jenkins et al, 2004).

With good reason, it is often said that such development is only cost-effective if a significant number of enabling factors are involved such as large student numbers, statutory or professional licensing, requirement for content mastery, and subject matter content or procedures involving exposure to hazard or expensive consumables. Where such factors are absent, routinely providing games and simulations does not currently meet sufficiently positive cost-benefit ratios, and because of the craft nature of development, is unlikely to do so in the future.

During the past decades, researchers have explored the effectiveness and impact of games that can be used as educational tools (Prensky, 2001; Gee, 2003; Becker, 2007; Girard, et al., 2012) and in supporting learning of STEM at any educational level. We can summarise the overall findings by saying that games and simulations can:

- facilitate students' inquiry,
- encourage them to engage in "What if" explorations,
- allow multiple and dynamic external visualisations through multimedia support,
- optimally communicate STEM abstract, complex and non-perceptible concepts,
- promote metacognitive skills, and
- support social interaction and collaborative learning.

Intended Learning Outcomes: ILOs

A pedagogically informed learning activity is based upon the existing competence of the learner, is coupled with prerequisite competences, and seeks to develop one or more articulated desired competences. A pedagogically informed (top level) competence is conceived as an acyclic directed graph of enabling competences, each competence (top level and enabling) comprising a contextualised intended learning outcome (ILO). An ILO in turn comprises a learned capability with respect to a specified topic or item of subject matter. Pedagogically informed teaching activities associated with the specified learning activities include the provision of appropriate materials, the assessment of learner performance on the desired competences, and the provision of feedback which is well-timed, contingent, and specific.

Ideally we would have tools for the routine every-day construction of cost-effective, shareable, reusable, and tailorable games and simulations as pedagogically-informed learning activities by 'ordinary' teachers and learners, in the same sort of way that learning materials are routinely constructed in support of one or more ILOs and assessments are routinely constructed to test the achievement of one or more ILOs.

In this paper we present a framework to tackle these issues.

Background literature

Multimedia has for some time been seen as an effective way to engage students and improve their learning (Woolf & Hall, 1995; Mishra, et al, 2007; Cherrett, Wills, et al., 2009). In STEM subjects this has manifested itself in terms of simulations and interactive multimedia activities which demonstrate a principle, process, or concept. In physics, for example, a set of simulations have been used to teach and assess undergraduates (Bacon, 1995; Bacon, 2010).

Studies by Roberts, Foehr, Rideout, & Brodie (1999), Bonanno & Kommers (2005), and Pratchett (2005) highlight gender differences in game categories with female gamers showing preference to music/dance and puzzle/board/quiz and classic games, while male players prefer action-adventure, racing, sports, and first person shooters. An interesting finding is the preference for simulations and Massively multiplayer online game (MMOG) genres in both genders (Pratchett, 2005). Ibrahim et al (2011) have developed an integrative framework that can support gender inclusivity in games, including a validated instrument to measure such inclusivity.

It is generally accepted that in order for people to learn they need to be engaged in the process; it helps if the student's mind is "mobilized". This is more than just physical activity; the learning activity also needs to feed the curiosity of the learner, encouraging them to construct their knowledge and link this to other concepts and procedures (Donovan & Bransford, 2005).

PEGS proposed toolkit

A toolkit is a model of a design or decision-making process, with tools provided at key points along the way. Each of these individual tools is designed to help the user access a knowledge base in order to make informed decisions. Toolkits "provide a pragmatically-based approach to applying theory to practice" (Conole et al., 2005) and can be used to support decision-making. A number of examples of successful toolkits exist; of particular relevance to this project are 'Media Advisor', and a toolkit to support evaluation. Media Advisor can be used to provide guidance on the appropriate integration of learning technologies into course redesign (Oliver and Conole, 2000), and the evaluation toolkit guides users through the process of creating a pedagogic evaluation strategy (Conole, et al., 2001).

With the purpose of addressing all issues discussed, we have developed a framework for integrating learning technologies into courses which builds on Laurillard's 'conversational' framework (Laurillard, 1993; Conole et al., 2001; Conole et al., 2005). The framework is designed to take the user through the thought processes of re-engineering a course to incorporate serious games, simulations, or adaptive formative assessments.

Pedagogical approach

To develop an effective framework for educational games and simulations it is essential to support pedagogically-informed statements of intended learning outcomes (Ambrose et al, 2010; Biggs and Tang, 2011). The relevant elements of such support are illustrated in the conceptual model of Figure 1.

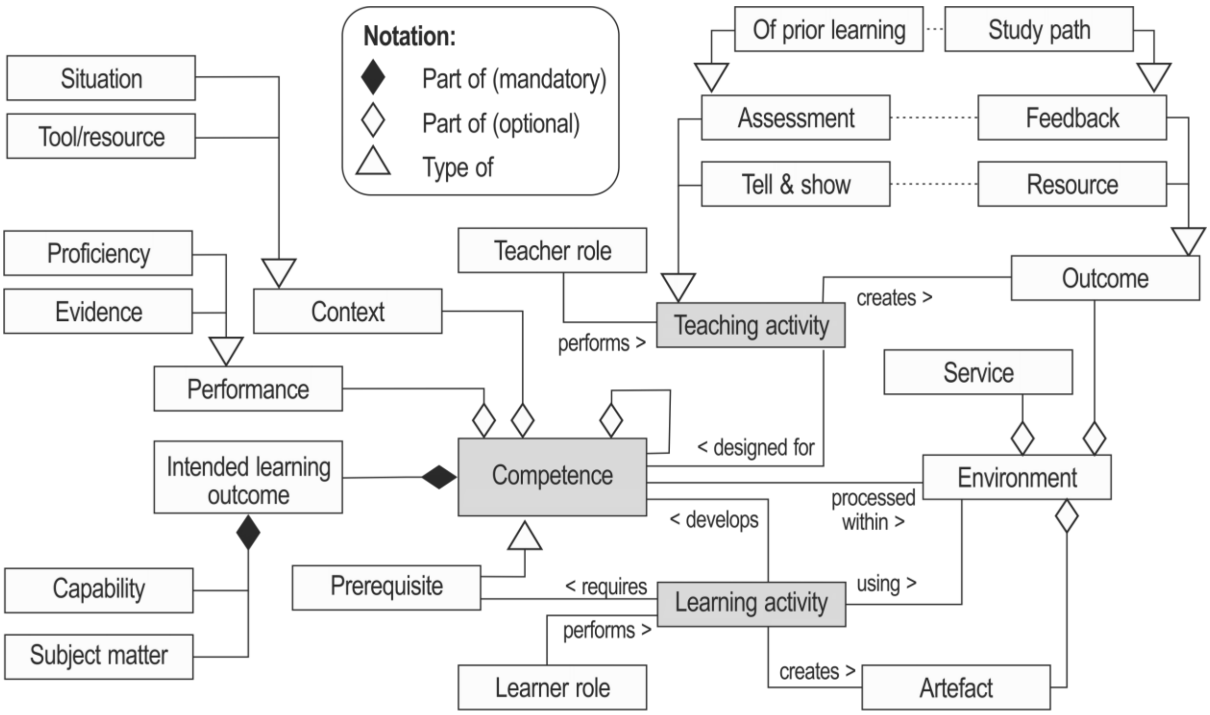

Figure 1. Conceptual model of intended learning outcomes and competence

A statement of an intended learning outcome is composed of a learned capability, often expressed using Bloom's taxonomy (Bloom, 1956; Anderson and Krathwohl, 2001), and its associated subject matter content, often expressed using Merrill's Component Display Theory structure (Merrill, 1983). The ILO identifies the educational purpose and suggests pertinent learning activities. Relevant teaching activities include the provision of learning resources and the provision of feedback. A competence is conceptualized as an ILO which is contextualized, has performance goals, and prerequisites. A particular topic comprises a network of top-level and enabling competences. The teaching and learning activities result in artefacts and outcomes which are held and processed in an appropriate environment.

Framework

The question we asked was *how can we construct and then take a machine-processable expression of an educational intention and (either automatically or semi-automatically) turn it into a computer-deliverable serious game, simulation, or adaptive formative assessment with (some elements of) pedagogical validity?* As a response, we propose a framework for Pedagogically Effective Games & Simulations (PEGS).

In such a framework, learners will be able to assess their current learning needs and navigate a machine-readable ILO structure to meet their learning goals. Each ILO will be associated with one or more learning activities. Where a learning activity is designed to feed the curiosity and reasoning processes of the learner, engagement and motivation is likely, allowing the learner to gain understanding and construct knowledge through their learning activity and consequential feedback.

A framework should allow for the 'routine' construction of cost-effective, shareable and reusable games and simulations as pedagogically-informed learning activities by teachers and learners who do not necessarily have gaming experience or skills. Such construction should take place in the same sort of way that learning materials are routinely constructed in support of one or more ILOs and assessments are routinely constructed to test the achievement of one or more ILOs. The framework should use open standards in the creation of games and simulations, thus ensuring continuous development and uptake by interested communities.

A framework should incorporate current thinking in educational research, where learning should be situated and authentic, with learners adopting an active and constructive approach. In particular, it should build upon the problem-based learning literature (Barrows, 1980), constructivism (Piaget, 1954; Papert, 1980), communities of practice (Wenger, 1998), situated learning (Suchman, 1988; Brown, Collins et al., 1989; Lave and Wenger, 1990), and activity theory (Engestrom, Miettinen et al., 1999). The proposed framework aims to create a toolkit and computer environment which allows the different benefits of each of these pedagogical approaches to be realized, supporting guidance and exemplars of how simulations and games can be used in learning activities and be included as part of a learning environment.

The PEGS Framework allows for simulations and games to be developed and stored using a 'toolkit'. This builds on our previous research on using toolkits to provide guidance and support, which are developed through a process of co-participation with relevant stakeholders. The pedagogical strategy is to invoke active learner participation supported by multiple resources made available in the learning environment. The learner participation involves searching for, evaluating, and using authentic information. This learning experience mimics real life in targeting the learner as the routine information hunter and interpreter who constructs knowledge by problem solving with information tools. The advantages to this strategy are the adoption of a student-centred approach to learning and the promotion of thinking skills (problem solving, reasoning, and critical evaluation).

We conceive a number of elements of a PEGS framework; the overall PEGS architectural model is illustrated in Figure 2.

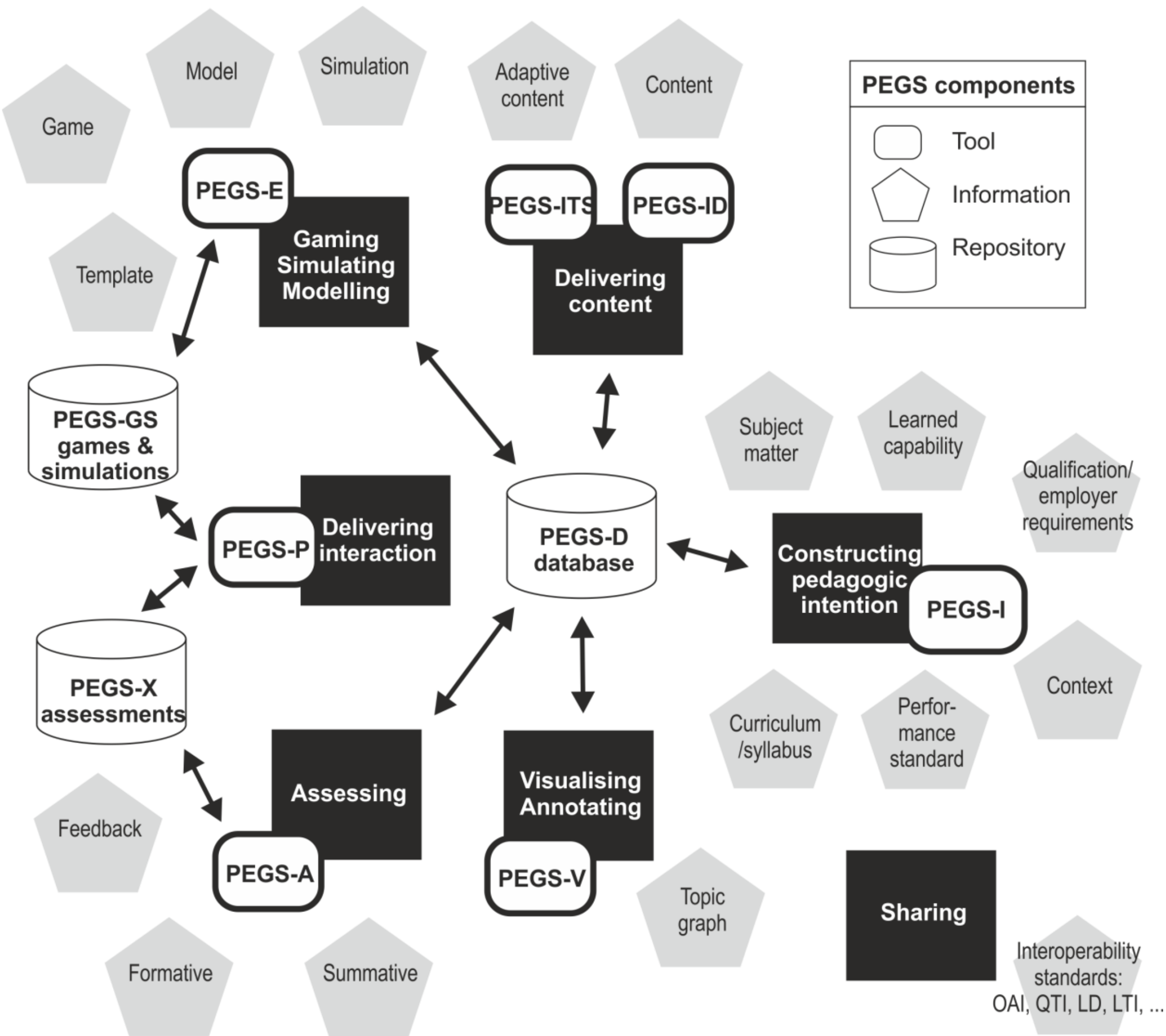

Figure 2. PEGS architectural Framework

The 'PEGS-I' tool is an application which supports a teacher in identifying and structuring intended student competences from syllabus and curriculum descriptions, from teacher expectations and desires, and possibly from national and international prescriptions.

'PEGS-D' is a standards-defined interoperable competences database which represents the topics of interest to a particular community.

Visualising the PEGS-D competences uses the 'PEGS-V' visualisation tool, which also supports exchanging PEGS-D competences with others, tagging key competences with supporting learning and teaching materials, etc.

One or more game and simulation templates are populated from PEGS-D to generate the desired learning activities using 'PEGS-E', the Editor. Templates may be pre-defined or developed from a 'blank sheet' or by adapting existing templates. The templates are standards-defined and interoperable (IMS-LD, IMS LTI, with extensions), yielding games and simulations which can be played using a compatible software application, the PEGS-P player.

The games and simulations are held in the PEGS-GS repository. The simpler games and simulations are single-user, the more advanced multi-player.

Assessments are generated using the 'PEGS-A' (assessment) tool and are held in a compatible repository, PEGS-X, as a standards-defined and interoperable (IMS-QTI, with possible extensions, and/or IMS LTI) file.

Finally, we envision a future 'PEGS-ID' tool to provide suggestions for teaching strategies and instructional designs which are appropriate to constituent competence sub-graphs in the topic, and an intelligent tutor, 'PEGS-ITS', to adaptively deliver materials and assessments.

Conclusions

The paper gives the background to a framework to support the 'routine' development of effective games and simulations from pedagogically-informed statements of intended learning outcomes. The framework aids us to address the problem of how can we construct and then take a machine-processable expression of an educational intention and (either automatically or semi-automatically) turn it into a computer-deliverable serious game, simulation, or adaptive formative assessment with (some elements of) pedagogical validity.

The intention of the framework is for learners to be able to assess their current learning needs and navigate a machine-readable ILO network. Each ILO will be supported with learning activities which will feed the curiosity and reasoning processes of the learners, which are gender sensitive, personalized, and adaptable. Learners will be engaged to gain their understanding and construction of knowledge through learning activities and consequential feedback.

The framework proposed is presented from the philosophical perspective of the pedagogical and technological underlying principles of a solution to bring serious games closer to educators. This analysis provides a theoretical foundation for future work which would be enabled by technologies that have not been defined or created. However, we envision that the framework will be delivered through a series of easily adoptable tool-kits. This approach would enable the 'routine' construction of cost-effective, shareable and reusable games and simulations as pedagogically-informed learning activities by teachers and learners, in the same sort of way that learning materials are routinely constructed in support of one or more ILOs and assessments are routinely constructed to test the achievement of one or more ILOs.

References

Ambrose, S.A., Bridges, M.W., DiPietro, M., Lovett, M.C., and Norman, M.K. (2010). *How Learning Works: Seven Research-Based Principles for Smart Teaching*. Jossey-Bass.

Anderson, L. and Krathwohl, D.A. (2001). *Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Longman.

Barrows, H.S. (1980). *Problem-based Learning*. Springer.

Bacon, R., Swithen, S. (1995). A strategy for the integration of IT-led methods into physics—the SToMP approach. *Computers & Education*, Volume 26, Issues 1-3, April 1996, Pages 135-141.

Bacon, R. (2010). The SToMPII QTI v2.1 assessment system and its use within the sciences. *International Computer Assisted Assessment (CAA) Conference*, Southampton, July 2010.

Becker, K., *Pedagogy in Commercial Video Games, in Games and Simulations* in Online Learning: Research and Development Frameworks, D. Gibson, C. Aldrich, and M. Prensky, Editors. 2007, Information Science Publishing: Hershey, PA. pp. 21-47.

Biggs, J. and Tang, C. (2011*). Teaching for Quality Learning at University: What the Student does*. Society for Research Into Higher Education.

Bloom, B.S. (1956). *Taxonomy of Educational Objectives*. Allyn and Bacon.

Bonanno, P., & Kommers, P.A.M. (2005). Gender Differences and styles in the use of digital games. *Educational Psychology*, 25(1), 13-41.

Brown, J. S., Collins, L., et al. (1989). Situated learning and the culture of learning. *Educational Researcher* 18(1): 32-42.

Cherrett, T., Wills, G., Price, J., Maynard, S. and Dror, I. E. (2009). Making Training More Cognitively Effective: Making Videos Interactive. *British Journal of Educational Technology*, 40 (6). pp. 1124-1134.

Conole, G., Miles-Board, T., Bailey, C., Carr, L., Gee, Q., Grange, S., Hall, W., Power, G., Woukeu, A. and Wills, G. (2005). Tool Kits for a Dynamic Review Journal. In: *EDMEDIA 2005 - World Conference on Education Multimedia, Hypermedia and Telecommunications*, June 27- July 2, 2005, Montreal, Canada.

Conole, G., Crewe E., Oliver, M. & Harvey, J. (2001). A toolkit for supporting evaluation. *ALT-J* 9(1): 38-49.

Conole, G. and Oliver, M. (1998). A pedagogical framework for embedding C and IT into the curriculum. *ALT-J*, 6(2): 4-16.

Donovan, M S (Editor), Bransford, J D.,(Editor) (2005) How Students Learn: Science in the Classroom. National Academies Press (January 5, 2005).

Engestrom, Y., R. Miettinen, et al., Eds. (1999). *Perspectives on activity theory. Learning in doing: social, cognitive and computational perspectives*. Cambridge, Cambridge University Press.

Gee, J.P. (2003). *What Video Games Have To Teach Us about Learning and Literacy*. Palgrave-Macmillan.

Girard, C., Ecalle, J. and Magnan, A. (2012), Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. Journal of Computer Assisted Learning. doi: 10.1111/j.1365-2729.2012.00489.x

Ibrahim, R., Wills, G. and Gilbert, L. (2011). Development of a conceptual framework for supporting gender inclusivity in games. In: *IADIS International Conference Game and Entertainment Technologies 2011*, 22nd - 24th July 2011, Rome, Italy.

Jantke, K.P. (2006). Games that do not exist communication design beyond the current limits. In: *SIGDOC '06 Proceedings of the 24th annual ACM international conference on Design of communication. Pages 35 - 42*.

Jenkins, H., Squire, K. (2004). Harnessing the power of games in education. *Insight*, 1(3), 5–33.

Laurillard, D. (1993). *Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies*. Routledge.

Lave, J. and E. Wenger (1990). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, Cambridge University Press.

Merrill, M.D. (1983). Component display theory. In C.M. Reigeluth (Ed.) *Instructional design theories and models: An overview of their current status*. Lawrence Erlbaum.

Mishra, P., Foster, A.N. (2007). The Claims of Games: A Comprehensive Review and Directions for Future Research. In: Crawford, C., et al. (eds.), *Proc. of Soc. for Information Technology and Teacher Education International Conf.*, pp. 2227–2232.

Oliver, M. and Conole, G. (2000). Assessing and enhancing quality using toolkits. *Quality Assurance in Education*, 8(1): 32-37.

Papert, S. (1980). *Mindstorm*. Basic books , New York.

Piaget, J. (1954). *The construction of reality in the child*. Basic Books, New York.

Pratchett, R. (2005). *Gamers in the UK: Digital Play, Digital Lifestyles*. BBC Creative Research & Development. December 2005

Prensky, M. (2001). *Digital Game-Based Learning*. McGraw-Hill, New York.

Roberts, D. F., Foehr, U. G., Rideout, V. J., & Brodie, M. (1999). Kids & Media @ The New Millennium: Menlo Park, CA: Kaiser Family Foundation.

Suchman, L. (1988). *Plans and Situated Actions: The Problem of Human/Machine Communication*. Cambridge, Cambridge University Press.

Wenger, E. (1998). *Communities of practice - learning, meaning and identity*. Cambridge, Cambridge University Press.

Woolf, B. P. and Hall, W. (1995). Multimedia Pedagogues: Interactive Systems for Teaching and Learning. *IEEE Computer*, 28 (5). pp. 74-80.