Educational Technologies and Learning Objectives

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***Abstract**: Technologies such as online tools, simulations, and remote labs are often used in learning and training environments, both academic and vocational, to deliver content in an accessible manner. They promise efficiencies of scale, flexibility of delivery, and face validity for a generation brought up on electronic devices. However, learning outcomes are not the same in all circumstances and sometimes contextual and cultural factors can lead to the failure of a technology which has been successful elsewhere. This paper draws on studies of the use of simulators and simulations within the vocational environment of the rail industry and uses Realistic Evaluation to assess and specify what works for whom in what circumstances. It is postulated that this evaluation framework could be a useful tool in the assessment of educational technologies used in engineering education.*

1. Introduction

Technologies such as online tools, simulations, and remote labs are often used in learning and training environments to deliver content in an easily accessible and realistic manner. They promise efficiencies of scale, flexibility of delivery, and face validity for a generation brought up on electronic devices. In engineering education there has been debate over whether technologies, such as simulation and remote labs, allow for specified learning outcomes to be achieved as successfully and as thoroughly as through conventional delivery techniques. Trevelyan (2004) asserts that learning objectives and outcomes do not differ significantly across technologies, while Lindsay (2005) suggests that different technologies promote different learning outcomes, and that this should influence how and when particular technologies are implemented. In any case, it is apparent that educators need a clearer understanding of the factors influencing the achievement of learning outcomes, because the pressure to use learning technologies as part of a blended learning environment is likely to remain.

Whilst established pedagogy can be used to help with implementation, it will not necessarily provide a complete framework for the educator. For example, learning theory recommends that learning experiences be conducted in learning cycles, through a sequence of:

1. orienting students to the learning that will take place and contextualising what is to be learned,
2. exploring and enhancing knowledge and skills through guided practice;
3. conducting independent practice of knowledge and skills; and
4. synthesising learnings in order to be able to transfer them to other contexts or environments (Killen, 2007).

This would suggest that simulations could be used to create a context for learning that activates prior knowledge, a setting for guided practice, a setting for independent practice, or a tool that allows disparate pieces of knowledge to be synthesised into practical application. However this is obviously the beginning of understanding how simulations may be used and further knowledge of the context and desired outcomes is required for successful implementation.

This paper draws on research currently being undertaken for the CRC for Rail Innovation, examining the use of simulators in the training of train drivers. There is concern in the industry that the substantial investment into the provision of full cab, full simulation simulators is not being realised in terms of driver training outcomes (Kavanagh *et. al.* 2008). Realistic Evaluation (Pawson and Tilley 1997) in which "what works for whom under what circumstances" is ascertained is being used to evaluate the use of simulators and the learning outcomes within the industry. The Realist approach is based on the understanding that the context of an implementation may activate different response mechanisms in different subjects, leading to different outcomes. Identifying the relevant aspects of context, subjects and their responses can explain why some interventions are successful in one area but not in another, or dwindle in their effectiveness over time. This paper presents two case studies in which Realistic Evaluation has been used to evaluate the use of technology and postulates that this methodology can be of use in engineering education.

2. Types of simulator and simulation

The rail industry uses a number of different types of technologies to train drivers, train controllers and guards. There are full cab simulators which mimic particular train cabs and provide drivers with a computer generated view of a virtual world outside the cab as well as real cab controls and occasionally motion corresponding to the computer generated view. This world may be manipulated by trainers to provide different scenarios and driving conditions. In addition, train sets are used for signal training, and PC based simulations may be used for route knowledge training. The corollary to engineering is that full cab simulation is comparable to a remote lab in that the students' experience is one of manipulating the world. PC based simulations, and scale models are ubiquitous in engineering education and thus a direct correlation can be made with these methods.

Simulations may vary according to the degree of reality presented and the aims of the training, as well as the prominence of role play, as Table 1 shows.

Table 1 – Types of simulators and simulations (based on RSSB (2007) p. 50)

	Part-task	**Full-task**	**Role play**
Conditions simulated	Narrow range, not all real world conditions simulated.	All or nearly all conditions simulated.	Usually manufactured dangerous conditions to address a particular need or skill.
Job performance required	Not whole performance, some aspect of job performance required.	Whole or near whole job performance required.	Performance required is relevant to conditions simulated, usually some aspect of job performance.
Delivery mechanism	Simple devices.	Complex devices.	Not a physical device.

Salas et al (2009, p.329) point out that the value of using a simulator in training "primarily stems from its ability to provide practice opportunities in environments that replicate important features of the 'real world' environment." In other words it may not be necessary to reproduce reality in its entirety and in fact there is significant basis for thinking that too much reality can be counterproductive (Dahlstrom et al. 2009). Indeed, findings to date indicate that student perceptions of the objectives of simulation play a significant role in achieving learning outcomes. For example, implementing maximum fidelity, to make the simulation as close as possible to the real world experience, can be counterproductive because this focuses student attention on the simulation rather than on the learning outcome and thus alters the student's perception of the simulation objective.

This is supported by Lindsay et al (2008) who state that "The learning needs of students evolve throughout their interactions with simulations" and that the reality of the simulation needs to be adjusted to the needs and expectations of students in their various stages of learning. In the rail industry, trainees who have not yet driven a train rate the usefulness of simulators highly, while experienced drivers repeatedly state "it is nothing like the real thing". Students are judging their experience in the simulation purely as a matter of traction control, how the train drives. New drivers have no experience with how a real train handles, thus a simulator provides useful training in that aspect of the job at that stage of their learning. This useful training is also achieved when experienced drivers use a simulator of a locomotive that they have not yet driven. At later stages of their learning this function of the simulator, traction control, is less significant. Other learning outcomes can be achieved and simulator fidelity of "train feel" is not crucial. These phenomena can be understood in terms of how simulators and simulations relate to the framework of Killen's (2007) cycle of learning.

3. Methodology

3.1 Realistic Evaluation

Realistic Evaluation seeks to discover not only whether a treatment or intervention works but how or why such treatment caused an outcome. Analysis of specific contexts, mechanisms of actions and the outcomes of an intervention is the key focus of realistic evaluation. Explanation of the mechanism that caused the treatment to work in a particular context allows for generalised principles to be applied to other contexts. Figure 1 is derived from the background literature and field observation and describes the context, mechanism outcome configurations which may be assumed to surround simulation-based training

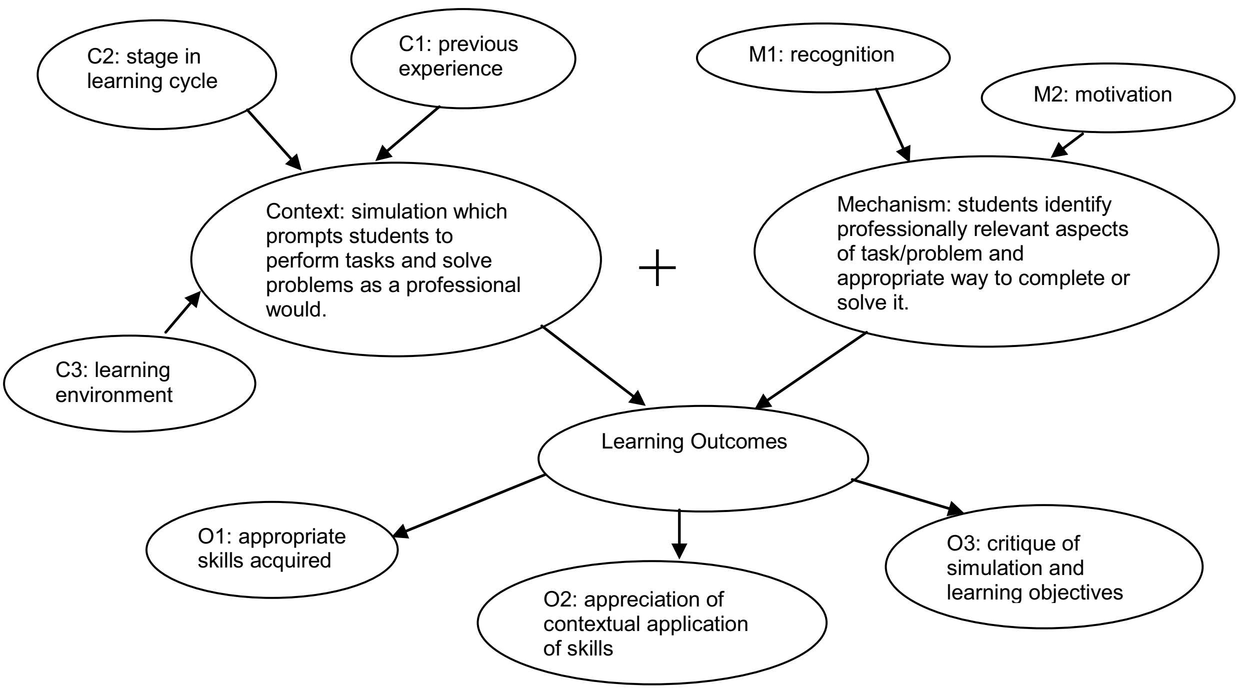

Figure 1: Realist representation of simulation-based training

In Figure 1 the context is affected by, amongst other things, the previous experience of the students and the stage they are at in learning this particular task. But it is also affected by the learning environment, by which is meant the whole design of the task including how students understand what is to be learned and why. Such factors influence their response mechanisms. Where the context allows students to identify correctly what the issue is and how to deal with it, they are more likely to attain the learning outcomes. However, the context needs also to motivate the student to accept the reality and importance of the task in hand for their future professional practice. Only then can the learning outcomes of attaining the target skill and appreciating how it is applied in practice be attained. Where the simulation fails to provoke the correct responses, the outcome is likely to be that students critique the simulation, ignore the key learnings and ultimately lose confidence in the training. It is the interplay of all these factors which make for success or failure and responses that deal with only one aspect, such as increasing fidelity in the simulation, will not necessarily be effective.

3.2 The case studies

Case One – Learning a new route in the simulator

The first case observed was in the training facility of a major urban passenger rail network. It was a day long training session with experienced drivers and guards held in order to familiarise them with a new route that they had not yet had the opportunity to drive. The objectives of the day included identifying station names, safe working practices, and evacuation procedures for the specific route. The morning was devoted to a classroom session which consisted of working through a printed handbook. The drivers and guards spent much of the morning reading and completing a workbook in conjunction with matching PowerPoint slides, but there was some discussion of the new conditions which drew on the students' previous experience.

The rail industry uses detailed diagrams of sections of track to record track layout, signal configuration, and speed limits. For a given section of track, an A4 size sheet is often crowded with detail and difficult to read. On this occasion, diagrams of 9 sections of track making up the new route were taped to the wall in the following pattern as shown in Figure 2.

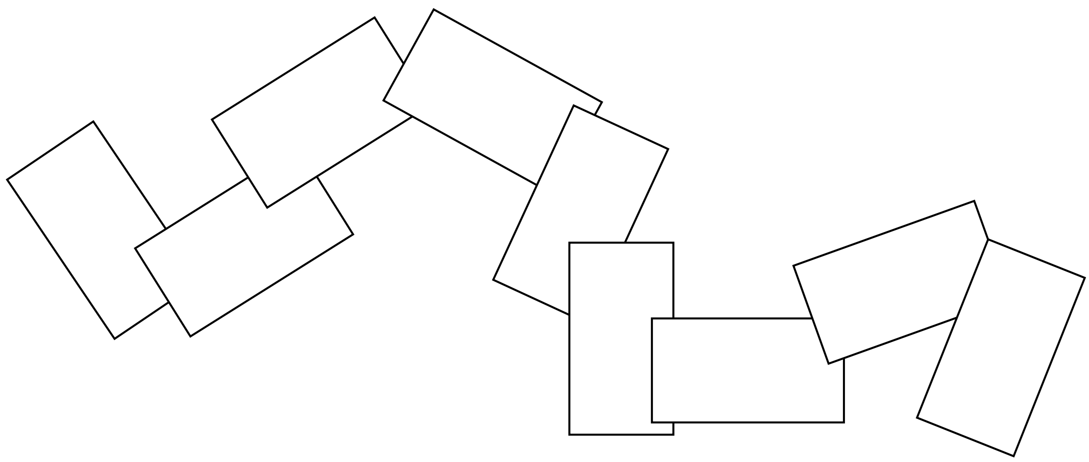

Figure 2: Diagrammatic simulation of new route

Drivers walking into the classroom recognised Figure 2 immediately as a representation of the curves and gradient of the new route, and commented on the difficulties that they might encounter. This can be seen as a part task simulation, as it reproduces a narrow range of reality, in this case features that the driver has to adjust to when driving. It draws on their prior experience and alerts them to what they have to learn which is where Killen (2007) suggests learning should start.

During the afternoon the drivers took turns in the full cab simulator. The route was represented by CGI which included the whole length of the route, including all stations. Drivers who had visited the new route commented that the simulation was "wrong" in some respects. For instance, tunnels were depicted as having a flat floor, when they were in reality rounded. This is a safety issue during evacuations where people have to climb down onto the track. Drivers also found that the CGI was not good at representing the lighting in tunnels and that the simulator did not provide "the feel of the train". This is a persistent complaint from train drivers about simulators. Despite extensive measures to increase fidelity including the occasional use of full motion, drivers maintain that the simulator does not give the feeling of momentum which acts as a driving cue for them. In describing this feeling they talk about driving "through the back of their chair" and seem to be referring to the experience of the weight of the train behind them. Drivers say that even full motion simulators do not replicate this feeling. There does not appear to be any technological developments aimed at providing more fidelity to simulate this experience of inertia but as previously mentioned, the aim should be to focus driver attention on learning outcomes which go beyond their physical ability to drive rather than to simulate the route more precisely. Certainly, in this case the drivers did not feel that their time in the simulator contributed to their ability to operate on this new route and perhaps a lower fidelity simulation which concentrated on route specific procedures such as managing an evacuation in the rounded floors of the tunnels would have been more acceptable to the drivers and guards.

Case Two – PC based part-task simulation

Case Two was a two day course for developing communication and team work skills in train control management staff from a large urban passenger network. The particular course observed had four senior personnel participants and five training staff. The activities were centred on a fictional setting and situation, where participants had to accomplish three separate 'missions'. During the mission each team had to complete specialised tasks within a time frame, the tasks were designed to emphasise teamwork and communication skills. A computer was used to represent the fantasy environment and track participants' progress on their missions in a manner similar to a computer game. The information provided by the computer was supported by instruction manuals and backup information that set the scene. Points were awarded for each mission with nominal target scores set, and team scores were compared against previous teams from the same organisation in a competition. In order to successfully complete their missions, participants had to work as a team to plan action in advance, and communicate well during the action. Roles were negotiated within the team and could be changed from mission to mission. There was an observer for each student who gave extensive feedback on performance at the end of each mission. The mission was video recorded and the facilitator used this recording for detailed discussion after each mission, highlighting relevant aspects of communication and teamwork skills. After considerable initial reluctance on the part of participants to take on the role play, they quickly became engaged with it. Participants were able to discuss the possible application of lessons learnt to the workplace and were enthusiastic about the effectiveness of the simulation.

In this case the simulation was not reproducing the participant's physical work environment. Instead it reproduced the factors that make teamwork and communication difficult in workplaces, namely workload, deadline and performance pressures.

4. Case study evaluation

Table 2 shows an evaluation of the Context, Mechanisms, and Outcomes of the two case studies.

Table 2 – Types of simulators and simulations (based on RSSB (2007) p. 50)

	Context	Mechanisms	Outcome
Case One	Experienced train drivers and guards learning new route through a) graphical representation and b) practice in simulator	a) recognition of familiar representations of job b) repudiation of simulation,	a) sustained technical discussion amongst drivers of implications of gradient, signal control changes and tunnels b) critique of technology rejection of experience, little learning
Case Two	Senior personnel practicing communication and teamwork skills in a computer-based fantasy environment	Acceptance of aims, procedures and pressures of the task as real Recognition of comparability with job	Identification of gaps in normal practice Articulation of changes that could be made to normal practice

		Motivation to complete simulation on its own terms	

These cases suggest that the type of learning to be achieved and the previous experience of the learner will influence the simulation to be implemented.

5. Discussion

5.1 Case studies

New learners need a different orientation to the learning outcome than those who are experienced in the task. The latter have to be able to link new information to information that will often have been acquired in a "real" context (Lindsay et al 2008). Lindsay et. al. (2008) then go on to suggest that this is an argument for using high fidelity at this stage of the learning cycle, but the real world comes in all kinds of forms and this takes us away from the main function of a simulation as a tool for delivery of particular learning objectives. Educators therefore need to pay attention to prior knowledge and experience, and to learning objectives. In Case One, involving experienced drivers, orientation to the learning was achieved by the pieces of paper stuck on the wall, which functioned as a simulation of the route to be learned. The papers could perform this function because the drivers were familiar with the representation of track in this format and could read the map with reference to reality. That is, it drew on relevant aspects of their previous experience as well as pointing out what needed to be learned. As a simulation this device lacked fidelity but it embodied a great deal of fidelity to the drivers' previous experience. They did not expect this map to represent reality in any more than an abstract sense and so they were able to read it as a sign of what they needed to learn rather than a reproduction of what they needed to learn.

The use of the full cab simulator in this case could be seen as being aimed at fulfilling Killen's individual practice stage of learning, which allowed drivers to practice what they had learned about the route in the early part of the course. However, participants rejected the usefulness of this learning tool because the fidelity of the simulation approached but did not replicate reality. As they focussed on the differences between the simulator and the real world, they were unable to take any learning from the experience at all.

However, for trainee drivers who have not yet driven a train, the full-cab simulator familiarises them with the controls, the amount of time it takes to stop, reading the signals, and other aspects that they have no previous experience of. The objectives of their independent practice is to master train controls such as brakes and the full cab simulators provide enough fidelity for them to do this. However, in the case we have cited above the simulator itself did not allow drivers to practice any of the learning objectives. The objectives were written in terms of "identify" and "understand" aspects of the new route such as station names and procedures. In fact the map represented by Figure 2 may have been more effective than using the simulator in achieving such objectives. We argue that drivers' generally negative attitudes to simulation arise from this kind of mismatch between learning outcome and the level of fidelity used. As per Lindsay et al (2008), the sense of reality to be achieved must match the learning needs of the students and not a photographic reproduction of the world.

This is illustrated by Case Two, in which the lack of reality of the simulation initially made orientation to the learning difficult for participants. It did not appear to draw on their previous experience nor was it obviously transferable to their current practice. The facilitator emphasised to the participants that the simulation was about communication and teamwork skills necessary to run the rail network efficiently and safely. The missions got progressively more complex and this, along with the extensive debriefing and feedback after each mission, provided both guided and independent practice of communication and teamwork skills. The debriefing also functioned to synthesise the learning and allowed participants to articulate for themselves ways in which it could be applied to their own practice. In this case, the simulation created an environment for learning rather than reproducing the practice environment.

5.2 The use of educational technologies

Educational technologies have to be evaluated in the context of their application which includes possible alternative strategies, historical factors influencing student expectations, and learning objectives. The principles laid out in Table 3 can be used in the implementation of educational technology. These principles, if applied to Case One, would have resulted in the use of a role play instead of a full-cab simulator, and for Case Two can be seen to support the existing delivery mechanisms.

Table 3 also connects to Realistic Evaluation as both Context and Mechanism are developed in order to secure a successful learning outcome (Outcome).

Table 3: Principles for the adoption of simulations

Stage of Learning Cycle	Learning Issues to be Considered (to provoke desired mechanisms)	Type of Simulation (Context of learning experience)
1. Orientation and contextualisation	1. Form and content of prior knowledge/practice. 2. Clarity of learning objectives in minds of learners.	1. Simulates prior experience in a form recognisable to learners, without extraneous detail. 2. Makes clear what learners need to concentrate on.
2. Exploring and enhancing knowledge and skills through guided practice	1. Minimal extent of new knowledge/practice to be presented. 2. Learning objectives reinforced.	1. Clear representations of skills to be practiced. 2. Ongoing feedback from teachers.
3. Independent practice	Allow for elaboration of knowledge/skills in independent exploration and/or collaboration with peers.	Sufficiently complex and responsive to mimic relevant aspects of practice environment. Allowance for collaboration/discussion/feedback.
4. Synthesising learning	1. Articulate what has been learned with reference to learning objectives. 2. Address transfer issues.	1. Present scenarios not yet used in training. 2. Simulate new performance conditions.

This moves the debate from the type of technology used to the type of learning to be achieved. Rather than specify type A simulation for stage X, it suggests what needs to be considered when instituting any type of simulation. For instance, in Stage 1 a high fidelity training simulator may accurately represent the end point of the learning but the steps a learner has to take to reach that end point may need to be made clear by supporting classroom strategies or by removing some fidelity features. Even very experienced practitioners in a high fidelity simulation can benefit at the independent practice stage from critique from peers who have observed their performance. No simulation can be expected to achieve learning objectives alone. They can only ever be part of a larger learning experience.

6. Conclusions

Educational technologies are becoming increasingly employed to deliver content in both vocational and academic settings. Research into the use of simulators in the rail industry has shown that these technologies require considered implementation in order to be effective and successful. The level of fidelity reproduced by the simulator must be appropriate to the experiences of the students. Students with little experience of the reality being reproduced may need higher degrees of fidelity to orientate them to the learning to be achieved. More experienced students may require lesser fidelity to allow for independent practise and synthesis of learning. The educator must be cognisant of the students' past knowledge and experience and must keep the learning objectives as the focus of the experience. Realistic Evaluation, which requires the educator to address the Context and Mechanism to ensure a successful Outcome, is a useful tool for this.

In the engineering context, this paper outlines a methodology to assess the effectiveness of online tools, remote laboratories and simulated experiments. As increasing diversity and increasing class sizes combine with generational changes in learning strategies, the effectiveness and limitations of these new learning activities should be measured. As educators we must ensure that we do not retreat to a "one-size fits all" position, even for new learning technologies. By better understanding how to assess "what works for whom and in what circumstances" we will be able to provide our students with a considered and effective suite of learning activities.

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