Using a Network Simulation Tool to engage students in Active Learning enhances their understanding of complex data communications concepts.

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Abstract

Computer networking concepts can be difficult to understand and teach as they frequently relate to complex and dynamic processes which are not readily visible or intuitive and are therefore problematic to conceptualise. Consequently teachers often incorporate simulation or visualisation tools to support the learning process, but often in a superficial way and without evaluating their effectiveness.

To tackle this issue we designed the practical sessions in a 2nd year undergraduate networking unit to use a network simulation tool, Packet Tracer ™, to facilitate active learning by providing an analytical, problem solving and evaluation framework. To then evaluate the effectiveness of using Packet Tracer ™ in this way, students were assessed before and after participating in one specific practical session. Measured results showed a marked improvement in student understanding of the topic presented (VLANs). We show that the use of the simulation tool, not merely to demonstrate concepts, but to also provide feedback and guidance enhanced deep learning.[1]

Keywords: simulation, evaluation, active learning, data communication, teaching.

1 Introduction

"It's not just the tool, but the educational rationale that counts" (Salomon, 2000). As Salomon implies, the sometimes automatic assumption that the use of a technology in itself will achieve deep learning outcomes is often misdirected. Indeed, while the use of technology in teaching can be perceived as *enhancing* the learning experience through the use of additional stimuli, for example, the use of multimedia, there is no clear cut corollary that this will *improve* deeper understanding. Mayer (2001) for example, maintains that including additional, but largely irrelevant multimedia material in a presentation, while interesting to the student, reduces learning performance. Our own experience has shown anecdotally that while students may *enjoy* using a teaching tool, for example, a visualisation package, their deeper understanding will not necessarily improve. Biggs (1999) refers to the *surface approach* to learning as an intention to complete a task with the minimum effort. Teaching tools can often unwittingly promote such an approach by making tasks too mechanical or easy to complete. So simply completing the steps in an exercise to simulate configuring a device will not encourage a deep understanding of the underlying process unless this is accompanied by appropriate cognitive elements. Rather if the tool could be used as a means of facilitating learning transfer, that is, by connecting established knowledge with new questions and situations, the student would derive answers through a deeper cognitive process. If the tool then was able to provide a framework for feedback, evaluation and guidance, errors or misconceptions could be corrected immediately as part of the deeper learning process. The importance of establishing a learning environment that so engages the student is even more apparent when the student needs to work independently and is removed from immediate teacher support.

Understanding networks and how networks operate requires an understanding of concepts and processes that are both complex and abstruse. This is made even more difficult because these cannot be easily seen or presented in a tangible manner. The use therefore of tools to demonstrate, simulate or visualise lends itself very readily to teaching in this area. Some tools, such as network analysers, are utilities used professionally in the industry and their very use in itself is an important skill. Others, such as simulators are expressly for the purposes of teaching and learning and here, it is important to focus on the purpose of the tool and how it is used, and not necessarily on the tool itself.

The benefits of using such tools in the teaching of networking is generally well accepted. However, our observations of student performance before and after a simulation tool was used simply for exercises and demonstration, has been that benefits could be more perceived than actual. We noted that even after students completed a set of exercises and reported that it went well, they had difficulties with subsequent exercises that anticipated the understanding of the earlier work. This was particularly the case if the students were working independently without direct or immediate teacher support such as when completing practical exercises.

To investigate the use of simulation in a more systematic, directed and pedagogically based framework, we were interested in examining whether using a simulation tool as part of an active learning process would achieve positive and consistent learning outcomes. To objectively assess this we undertook an experiment to evaluate the real effect by measuring the actual change in learning outcomes in a specific practical session

Within the context of a normal second year undergraduate unit in internetworking, we designed an experiment based on the normal practical exercises. The simulation tool we used was a network simulator Packet Tracer ™ developed and distributed by The Cisco Learning Institute and used with permission of QUT's Cisco Networking Academy Program. This simulation tool was used as an integral part of the practicals and students were familiar with its functionality and operation. As was our usual practise the practical exercises were based on material introduced during an earlier lecture. The only departure was that there was to be no teacher involvement at all in order to fully evaluate the effect on independent learning.

Students attended normal practical sessions but were evaluated prior to commencement to assess their current understanding of the material. They were then given the practical exercises which were designed to engage them in active learning through the use of the simulation tool. At the end of the practical session students were given a post test similar to the initial pre-test.

We found that student understanding appeared to improve considerably and concluded that the use of such tools in the context of active learning enhanced the effectiveness of the tool.

2 Background

Active learning can be defined as "instructional activities involving students in doing things and thinking about what they are doing." (Bonwell 1999). In this context, Bonwell further contends that a framework that encourages students to engage in active learning should include higher-order thinking tasks as problem solving analysis, synthesis, and evaluation. Such a framework challenges the student to learn through transfer and encourages deeper understanding. In a teacher-led environment, a teacher can generate this through good instruction, guidance and dynamic interaction. The problem facing us was how to achieve this in a situation where there was no direct teacher involvement and the student was only interacting with the simulation software.

To this end we designed the practical session that we would use in the evaluation so that the students would need to answer a series of questions about a progressively more complex switched network environment. They were able to assess and correct their answers at each stage by observing and analysing actual network behaviour through pre-configured scenarios. Questions were built incrementally so that later questions referred to concepts covered in earlier ones. This provided the framework for "analysis, synthesis and evaluation" (Bonwell 1999). The incremental nature of the exercises and their interdependence was aimed at facilitating a transfer of learning which occurs "when learning in one context enhances (positive transfer) a related performance in another context" (Perkins & Salomon 1992). In our situation, concepts learned in earlier stages of the practical were necessary to understand later ones.

One of the main issues we had to consider was how to measure any changes in understanding. After an intensive review of existing work we found that there was relatively very little that utilised a formal evaluation when evaluating learning outcomes in the area of data communication. Two examples where evaluations were carried out were Cameron (2003), and Yaverbaum (1996). Both apply a number of tests and then compare the results of these. In similar vein we decided to employ a pre-post test instrument of evaluation based on the proposal outlined in Naps (2002).

Determination of the simulation tool to use in an investigation of this nature is also highly relevant and dependant on a clear understanding of what the objectives of the investigation are. For example, if the simulation tool itself is to be evaluated then the experiment would be less interested in the design of the tool (this is being evaluated) and may be more interested in ensuring that no respondent has a greater degree of prior familiarity with the tool (to avoid pre-conceptions or to be able to indeed measure the difficulty of using the tool). In our experiment we wanted to evaluate the *effectiveness* of the simulation tool when used in the context of independent active learning. We therefore wanted to eliminate as much as possible any factors that might have detracted from the learning experience, for example, any complexity or difficulty in actually using the tool. Similarly, we wanted to conduct the experiment in a "natural" environment, as part of the continuum of study making up the unit and did not want students to be distracted by having to learn to use the tool.

It was therefore appropriate and convenient to base the experiment on the major simulation tool that was already part of the unit make-up. Students were familiar with the tool and competent in its use. Furthermore, using the tool in an active learning framework was already part of the practical exercises. The practical session in which we intended to conduct the actual evaluation would therefore be a normal session, covering material relevant to what was currently being discussed in the unit, and would use a tool with which the students were already very comfortable. The only difference was that in this particular session students would only engage in independent work and there would be no teacher led component. Our aim was that the evaluation would measure the actual learning outcome from a typical unit based practical session.

3 Experimental Design

In designing the practical exercises for this experiment we also needed to consider the nature, functionality and capabilities of the simulation tool. The simulation tool that we used in this experiment, and which is also extensively used in the unit, was Packet Tracer ™. The simulator enables a simulated network to be built in a topography view by connecting a range of network devices (routers, switches, bridges, hubs, servers and PCs) together using a variety of connection media and then configuring the devices appropriately. Interfaces can be set and routing tables can be built. The network built can be extensive and the specific capabilities of individual devices are also available. For example, switches can be used to implement Virtual Local Area Networks (VLANs) and dynamic routing can be applied. In simulation mode, Packet Tracer ™ enables data packets to be created and sent from device to device. The behaviour of the packet and the route it follows simulates the way a packet will act in an actual network. Errors in the network configuration, for example, incorrect routes, will therefore cause a data transmission to fail and this is shown in the visualisation. Furthermore, at each hop in a transmission, the state of a device as well as the message headers in a packet can be examined. This makes it a powerful tool for not only practising network configuration but also, by observing network behaviour and then analysing the network and packet status, the cause and effect of a particular configuration or setting can be identified, confirmed and understood. It was especially this aspect of Packet Tracer ™ that we saw as facilitating an engagement in active learning.

In keeping with our usual practice the material used in the evaluation practical was taken from the preceding week's lecture. The subject we looked at was "Switched networks and VLANs". The practical exercises were then based on 5 concepts taken from this area; collision domains, broadcast domains, switching, VLANs and inter VLAN communication. For each of the topics, a separate Packet Tracer ™ network layout and configuration was built. For each topic as well a series of questions were designed to test understanding of that topic (remembering that this would already have been covered in the lecture). Similarly, for each question in each topic a simulated scenario was included that implemented and showed the situation referred to in the question. So, if the question asked how a packet would be routed from node A to node B, the corresponding scenario would actually show this a simulated packet sent from A to B. In the practical session students would be asked to open the simulated network, examine the network shown in topography (layout) mode first and then answer the questions based on their understanding. They would then be asked to switch to the simulation mode and run the scenarios for each question to confirm and evaluate their response. If their answer differed, then, by analysing the scenario and looking at the device or packet configuration at each step of the process, they would be able to learn what went wrong and why. The simulation would provide them with the framework for analysis, synthesis and evaluation. On completion of the topic a broader question would be asked to lead them to the next topic. Because the topics increased incrementally in complexity, questions in later topics required understanding gained in earlier ones and indeed, questions asked in the later topics referred to earlier ones by also examining comparative differences.

To assess and measure the change in learning outcomes, we designed our pre and post tests to consist of 10 multiple choice questions covering the topics included in the practical exercises. The questions focussed essentially on *understanding* and not on reviewing information. As Naps (2002) also suggests, the tests were designed to be isomorphic so that we would be able to assess understanding of the same concepts pre and post undertaking the practical. Prior to commencing the practical, the understanding would be based on what was learnt from the lecture (and existing knowledge or experience). The test administered immediately at the end of the session, would then measure any change brought about as a result of the practical. To avoid identification of the same question, and possibly then giving an answer based on the first (pre-test) answer, the questions in the post-test were re-ordered and re-worded. The post-test also included a question asking the student to rate their perception of how they felt the simulation program had helped in their understanding of the concepts. This question was of course not included in the calculated results.

We were aware that our body of students, even though a second year undergraduate cohort, nonetheless included students of different backgrounds and varying levels of both prior study and professional experience. We wanted to isolate such variables and we therefore included a short general questionnaire covering some basic demographics (for example age, gender, prior experience and knowledge) and personal perceptions (how they rated their overall understanding of the unit material).

In our experimental design we identified and associated the questionnaires by a randomly allocated ID number that would only be known to the individual student.

4 Implementation

The experiment was conducted with the approval of the University Human Research Ethics Committee and was authorised at the level 1 (low risk) category. Because attendance in practical sessions is not mandatory, students were informed of the experiment and asked to attend their practical session as usual. It was made clear to participants that all personal information gathered would remain anonymous and that there would be absolutely no relationship between the outcomes of the control tests conducted and their unit results. The practical was given in the normal time slot although the time for the session was extended to allow students to complete the exercises during the allocated time and not continue in their own time as would usually be the case. Again, because of the size of the group and available laboratory space, five repeat sessions of the practical were given.

At the start of each session students sat at individual workstations in the normal way and were provided with mandatory information about the conduct of the experiment. Students were then asked to randomly select a set of four id labels from a box and were asked to affix the first label to the general questionnaire and then to complete this. The pre-questionnaire was then distributed, students instructed to affix the second id label to this questionnaire and then again to complete this to the best of their ability. Once this was done, the actual practical exercises were handed out and the students were able to proceed with the exercises independently and at their own pace. No support was given in answering the exercises and the only help provided was to clarify a question (mostly in the case of students for whom English was not their first language) or if there was an operational problem with the software (which actually did not occur). Although students were not prevented from talking amongst themselves, we noted that they very rapidly became engaged in the exercises and immersed themselves in their individual efforts.

Once the exercises were completed the final post-test questionnaire was distributed and completed by the students. The last two id labels were used to identify the post-test and the actual set of exercises themselves. We had decided to collect the exercises in order to avoid the possibility of later groups looking at or discussing these with students who might have done the practical in an earlier session. (The exercises were later returned to those students who wanted them)

Because classes for the unit were delivered on two campuses, we were able to run the practical session on the second campus with a smaller group of respondents using a tutor-led format. The same concepts were covered and we again conducted the same pre- and post tests. We had hoped to compare the 2 groups but statistically, because of the nature of the sample population, we were unable to analyse this second group as a control group. General results and observations however indicated that the achievements were similar to that of the simulator based sessions and that there was an improvement after the practical session.

5 Results

66 students participated and responded to the pre- and post- tests. However, 6 were excluded from the analysis because of missing data.

To consider the overall results each student's pre- and post- test was marked out of 10. In the pre-test the average mark was 55%. In the post-test this improved to 67%, an average increase of 12%. (Table 1)

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	POSTOTAL	6.67	60	1.56	.20
	PRETOTAL	5.55	60	1.54	.19

Table 1: Paired Samples Statistics

The difference between pre- and post- tests was shown to be statistically significant (Table 2). We calculated the standardised effect size to be d= 0.63 suggesting that participation in the practical session was a significant factor in improving the understanding of the concepts presented

Pair 1	**t-value**	**df**	**Sig**
Postotal-Pretotal	4.89	59	<0.01

Table 2: Paired Samples test

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In terms of individual results, 63.3% of the students improved their results in the post-test, 18.3% showed no change but 18.3% actually showed deterioration. However, the average improvement in marks for those who did improve was 23% while those did worse went down by an average 15%. There is no clear reason why some students did not improve their results since this was not confined to any single identifiable group. Factors such as becoming confused, not being as familiar with the analytical functionality of Packet Tracer ™, or simply guessing might have played a role and this will require more investigation.

On a question by question basis, overall there was an improvement in the responses for eight out of the ten questions. For one question there was no change and for one the results in the post-test were actually worse. This could have been related to a difficulty in understanding the question. The average improvement for individual question scores was 12%. (Table 3)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Ave
Pre	45	52	36	22	11	47	27	40	30	23	33.3
Post	59	54	33	41	17	52	27	44	53	27	40.7
Diff	14	2	-3	19	6	5	0	4	23	4	7.4
%	23	3	-5	31	10	8	0	6	38	6	12

Table 3: Individual Question Response

In our general questionnaire we collected demographic data to use for further analysis. We also collected data relating to the students prior IT studies, their IT professional experience and their self perception of their understanding of the material taught in the unit. We conducted a ANCOVA test to see whether these factors influenced the change in performance and while there were some indications that they did not, that is, change was uniform across all groupings, statistically this was inconclusive since some of the group sizes were too small.

We were also interested in investigating whether the group factors had any correlation to the pre- and post-test scores. That is, did students with prior studies, prior experience or a higher self assessment obtain a higher result for the pre-test and then the post-test. Again, this was inconclusive. However, while prior study and prior experience did not seem to correlate with the results, there were indications that there was a correlation with self assessment of general understanding of unit material. (Table 4).

UNDRSTAND		PRE	POST
Very much	Mean	7.00	10.00
	N	1	1
	Std. Deviation	.	.
Most things	Mean	6.00	7.00
	N	26	26
	Std. Deviation	1.38	1.49
Some things	Mean	5.23	6.53
	N	30	30
	Std. Deviation	1.61	1.30
Very little	Mean	4.33	4.00
	N	3	3
	Std. Deviation	1.15	1.00
Total	Mean	5.55	6.66
	N	60	60
	Std. Deviation	1.54	1.55

Table 4: Student Self Assessment of Unit material

It would appear that the more students felt that they were coping with the unit overall, the greater was their improvement in the post-test. Indeed, students who rated themselves poorly actually went down in performance, suggesting that the exercises perhaps confused them further. Aside from the experiment, this signalled the need for some additional support for these students..

6 Conclusions

The primary objective of this experiment was to investigate and measure the change in understanding that occurs when a simulation tool is used to facilitate active learning.

The practical session was structured to promote active learning by progressively leading the student through the concepts presented in an incremental manner that challenged the student and forced them to synthesise, interpolate and apply knowledge already learnt. As part of this process they needed to be able to assess their answers, receive feedback and correct any misconceptions before progressing further. In-so-much that there was a measurable improvement in understanding, we are led to surmise that active learning did occur and that in our context it was facilitated by the way we were able to use the simulation tool.

Because the post-test took place immediately after completing the practical exercises, we concluded that deeper learning occurred as part of the practical session and not because of any review or consolidation.

Anecdotally we believe that the simulation tool used in this manner was more effective than if just used to exercise or to demonstrate concepts although we are unable to quantify this at this stage. Such comparative assessment is something we plan to look at as part of further investigations.

From the conduct of the tutor-based practical session on our second campus we can confirm that improvements in student understanding can be achieved using other methodologies as well, something that would appear quite obvious. However, these different methodologies engage different dynamics and require differing environments, and consequently can serve diverse needs Again, a comparative study would be of interest as would an assessment of retention; that is, whether the student retains the understanding gained, and the impact this might have on final exam performance.

For this particular experiment it was our main intention to measure one particular approach and to examine its effectiveness in providing a framework for the conduct of an active learning, self-engaging, individual-focused practical exercise that could provide a, consistent result in a defined time and within the context of prescribed course activity. The use of the simulation tool in this manner appeared to be successful

It remains the decision of the teacher on what method to use and what approach best suits their specific needs, For example, in situations where a student might have to work independently such as in distant education, such a structured active learning approach as we employed might be particularly useful, while in teaching certain concepts, tutor led discussion might be more appropriate. Our intention was not to judge which approach was best but rather to confirm the effectiveness of this specific approach.

In Packet Tracer ™ we found an excellent instrument that enabled us to achieve independent active learning. Packet Tracer ™ was able to be used not only to demonstrate and exercise network related situations, but its facility for building dynamic scenarios and assessing the state of the network and the packet transmission at any point was crucial in enabling us to provide a feedback, evaluation, correction and analytical framework. While it may not be feasible or even desirable to always use a simulation tool in this manner, we concluded that with the appropriate tool active learning can be encouraged and enhanced.

Being able to interact independently with the framework (Packet Tracer ™) and the dynamic and exciting nature of this tool seemed to have positively challenged and engaged the students since not one of those participating left the practical before completing the exercises even though they were under no obligation to remain. Indeed, a question in the post-test that asked for their own perception of how the practical session, and use of Packet Tracer ™, had enhanced their understanding of switching and VLANs, received a universally high and positive rating. We believe that the level of comfort and even enjoyment in using the simulator is important as it encourages the student to engage this tool positively and does not require that the student over-invest their time and effort in simply operating the tool

It was interesting to note that students immersed themselves in the exercises and did not ask others for help even though they were not discouraged from talking to each other. It appeared that this was obviated because they were able to resolve issues for themselves through the active learning process and engagement in the scenarios.

We plan to conduct further work in this area and to also look at comparisons between the effects on learning when using the simulation tool in different ways and in different contexts. Similarly, we would like to look at the effect of other comparative methods in teaching similar concepts. However, in the current case we concluded that if exercises using an appropriate simulation tool are suitably designed to actively engage the learner, a clear improvement in understanding is achieved.

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