Understanding physical phenomena through simulation exercises

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Abstract. Traditional lectures and exercises are good for gaining basic knowledge in STEM (Science, Technology, Engineering and Mathematics). If feasible, motivational and deeper learning experiences like laboratory- or work life-related field experimentation are included in studying levels, more concrete learning experiences can be reached. At the National Defence University (NDU), the theoretical part of master’s level studies in STEM relies on earlier basic studies. In order to promote practical skills, a specific simulation and modelling course is aimed at learning how real-world artifacts or models work, how to acquire data, how to visualise the acquired data, and to develop one’s understanding through simulations. This course ends with a group work, where participating students are asked to produce a working simulation model either from the given list or from their professional context. This study describes two sample cases: The first one is a flight simulator that includes a lot of physics and physical phenomena. The second one illustrates time dependence and statistical nature of targeting. The course’s success is estimated from reports and the feedback given by the students. Observations on motivation and learning goals are included. For military officers learning is practically oriented, while in natural sciences learning is theoretically oriented. In both cases simulation is a natural “bridge” in between theory and practice.

1. Introduction
Many studies have identified problems in Science and Technology education [1]. Some studies claim that instruction should be discipline related, context specific and also that certain instructional strategies are more prominent than others [2]. It is claimed that misunderstandings about the physical world and phenomena are common among students in spite of the apparent skills of the teacher or students’ earlier physics courses in secondary school. The Newtonian framework is the key to understanding non-relativistic motion. For example, when using a conceptual framework based on Newton’s laws of motion, the student may understand that, in the simplified model, a body moving at a constant velocity requires no net force to keep it moving and so no residual forces are required. [3]

In military technology education, lectures and exercises are aimed at introducing scientific methods and mathematical tools that support professional practice and may be applied in an officer’s profession. Officers need to be able to apply theoretical knowledge in practice. In general, military training, planning and design include multiple ways of preparing students so that they reach the needed readiness and skills. Due to the fact that there is a huge variety of battlefield scenarios as well as ways of utilizing high-tech weapons, the battlefield environment needs to be modelled. [4] Quite often demands for such simulations are related to the visualisation of specific data with a suitable high-level toolset [5].

For simulation and modelling purposes, commercial and academic software has been developed. Some of it is highly specific while other software can be tuned with a set of tools from the developers’
library. This includes but isn’t limited to Matlab [6], Vissim [7] (has been rebranded and embed as a part of solidThinking's Development Suite) and Berkeley Madonna. [8]. On the other hand, traditional Visual Basic for Applications (VBA) has been widely used in mathematical modelling and simulation as a general or introductory tool for studying the features of any presented problem [9]. Therefore, this tool was selected to be used in most of the simulation courses at NDU.

2. Motivational aspects and team efforts
Studies show that intrinsic motivational factors are strong among cadets [10] and that on the other hand, master’s level students in NDU have mature, professional attitudes. However, extrinsic motivational factors also have a meaningful role in instruction. At NDU, the importance of a courageous team spirit is generally highly emphasised. This means that the dialogue between lecturers and students is maintained throughout the educational activities in courses. From this, it follows that interaction is typically open and vivid between team members, between different teams, and with lecturers. This also forms a solid foundation for motivational aspects and therefore, interaction intensity is typically given special attention when evaluating different learning situations at NDU.

3. Methods and Material

3.1. Action research as a Method
Action research is designed to bridge the gap between research and practice. This method guides towards real intervention, includes evaluative work and produces information that helps to find a better approach. Therefore, enhanced interventions are often seen as a cyclic process [11]. Simultaneous and long-term findings give signals on how to streamline and mature teaching procedures in STEM education at NDU. Flexibility and creativity are emphasised in this method, which makes it very useful in the context of NDU, where rapid changes are often made. The purpose of this iterative process in this study was to produce better instruction.

NDU collects feedback from each course. The presented remarks were based on the course held in 2016. Observations were focused on learning results, motivational aspects, and common impressions of courses. It is known that student evaluation of teaching (SET) in higher education still has challenges concerning its validity [12]. Local standard SET questionnaires on NDU’s learning material portal (Moodle) were used for data collection, comparison, and storage. Qualitative conclusions were formed from multiple sources and the main findings were discussed with instructors and students to verify that the facts behind both formative and summative results were relevant. This study focuses on the following questions: 1) Are master level students able to create artefacts (simulators) which emulate real world by using equations or statistical models? 2) Is exercise centric learning method successful and how it was perceived by the students?

3.2. Course structure and educational aspects
Master’s level students majoring in NDU’s technology programme have different instructional needs. Therefore, the current study aims to explore how a relatively practice-oriented simulation course would affect students’ motivation and attitudes towards physics and technology as professional tools. Specific observations and data are from sixth implementation of the Simulation and Modelling Course (SMC). The instructional structure of this course consists of three overlapping teaching methods: lectures, supervised exercises, and unsupervised exercises. At the course introduction students are asked to produce a working simulation model either from the given list or from their professional context. At the end of the course student groups present their unsupervised exercises. The final report consists of documentation and the functional version of the group’s own specific simulation realisation. Up until now this course has been carried out seven times with only slight modifications.

In the situation at hand (spring 2016), the whole course consisted of 21 students (N=21). They were divided into 5 teams, and each team was tasked with producing a demonstration case. As aids, different toolkits, mathematical theories, and simulation models were at hand. From this implementation two
excellent works were taken for further analysis (Case 1 & 2). According to the instructor’s evaluation these two teams were asked to present their results to the whole course group. In addition to their excellence, these cases were also selected due to common interest in these demonstrations. Furthermore, this possibility offered extrinsic motivation value of a kind that is connected to a reward system [13]. The purpose of this course was to inspire young officers to apply their skills and knowledge in a new creative way and create a shared team learning situation. Lecturers had a minor consultative role in this assignment.

In the first case (case 1), future fighter pilots tested how well they could simulate some functions of their future (real) training jet plane. In the second case study (case 2), another group presents how statistics could be used to model the movement of the target while a projectile travels from its launching pad toward the target point. Due to practical reasons only, a limited number of real missiles can be launched for testing, so the question was: “is there any chance to get statistical data through simulations”.

The profession of an officer involves the utilization of advanced technological artifacts (e.g. weapons, weapon systems, or supporting trunk systems). To make the simulation tool more operative, it was necessary to find a simple set of requirements for the simulator for the first stage. Once the tool was good enough, a further requirement was that the usage of the simulator had to be easy enough for an average officer to be able to use it after a few minutes of instruction.

The importance of this study relies on the fact that normally, only some of the students have any prior programming experience whatsoever, which was also the situation in the sample course. In general, VBA tools are usable for military-type simulations [14]. This kind of continuous successful usage of VBA by students is a strong empirical testimony of its usability in general. This paper presents observations of how a group of average officers with no major prior coding experience were able to create a working simulation application using VBA. The scheduled time for doing the work was 8 weeks. Research suggests that simulations can improve the efficiency of learning [15-17]. At NDU, instead of learning directly from the simulation, students actually create the simulation model, enabling learning while solving the problem [18].

3.3. Remarks on VBA in Excel®
VBA [19] is an implementation of Microsoft's discontinued event-driven programming language, Visual Basic 6, and its associated integrated development environment (IDE). It enables building user-defined functions (UDFs), automating processes and accessing Windows API, and other low-level functionality through dynamic-link libraries (DLLs). It supersedes and expands on the abilities of earlier application-specific macro programming languages. It can be used to control many aspects of the host application, including manipulation of user interface features, such as menus and toolbars, and working with custom user forms or dialog boxes.

VBA is built into most Microsoft Office applications and other Microsoft applications, including Microsoft MapPoint and Microsoft Visio. VBA programs can be attached to a menu button, a macro, a keyboard shortcut, or an OLE/COM event, such as the opening of a document in the application. The language provides a user interface in the form of UserForms, which can host ActiveX controls for added functionality.

The programming language behind Excel - VBA - is an interpreted language, which means that algorithms coded in it might execute slowly. For wider utilization there is the assumption that all potential users of the simulation will have access to Excel and preferably a particular version - some versions of Excel have not been completely backward compatible. Also some localization issues of the Office environment may be encountered.

4. Case1, Understanding Aerodynamics
The use of technology to simulate physical phenomena probably found its first application in practice in the “Blue Box” developed by Edwin Link in the 1928. The “Link Trainer” flight simulator was used to train thousands of military aviators. [20] The first implementation (case 1) is a fully working PC
simulator (covering limited functions) of training scenarios of the Hawk aeroplane. Generally, students face difficulties in studying motion and related issues [21]. In the first case (case 1), the students utilized earlier learning experience and produced a fully realistic simulator with certain functions. Before getting to practise with their own simulator, students browsed their aerodynamic learning material in order to list all relevant physical phenomena and listed them:

- An upward thrust (wing, elevator and tail), where we need the following inputs: a) affected areas, wing configuration, speed, Mach, air density, flying angle etc. b) the decrease in the upward thrust after stalling and the movement of the pressure centre towards the back of the plane. c) The movement of the pressure centre in the transonic area, the head down effect.

- Resistance (structure, wings, tail): a) Induced and parasitic. Transonic resistance. b) Same inputs.

- Engine: a) Produces thrust even when idle. Thrust will change as a function of the Mach number, air density, and rotational speed. b) Modelling the nonlinear dependency between thrust and revolution.

- Flaps, brakes and landing gear: a) Flaps have two positions. b) Modelling of the landing gear, consider frictions and shock absorption. A hard landing will break the airplane.

- Wind: when height increases, blusters affect the direction and may change the speed.

To get a well-behaving simulation that corresponds to real-world artifacts, the correct parameter values for the specific aeroplane were needed. Luckily, the students were able to gain this information. In order to estimate how well their solution worked, students made a comparison between the manufacturer’s data and the performance given by their simulator. Table 1 is a direct translation of the students’ course report (table 1). To test the touch, students added a real-time control interface to fly the simulator and follow procedures from the simulated cockpit view. Figure 1 is taken from the course report and it illustrates how the simulator’s graphical interface on the right imitates the real cockpit view seen on the left-hand side of the picture.

Table 1. Comparison of the simulation and the aeroplane’s factory data, M abbr. for Mach (speed), G - relative acceleration, and Kias abbr. for Knots in air speed.

| Test                                      | Simulator | Reality    |
|-------------------------------------------|-----------|------------|
| Time taken to ascend to 11 km (weight 5000 kg) | 10 min 50 sec | 10 min 50 sec |
| Max horizontal velocity and G-value       | M 0.81 and G 5,0 | M 0.805 and G 5,5 |
| Stalling speed (Load/ weight 5000 kg)     |           |            |
| Level flight                              | 120 Kias  | 124 Kias   |
| Takeoff                                   | 109 Kias  | 111 Kias   |
| Landing                                   | 100 Kias  | 105 Kias   |
| Max Banking force at Level Flight Speed @ 10 000 ft | M 0.84 G 3.8 | M 0.845 G 4.0 |
| @ 30 000 ft                               | M 0.86 G 1.9 | M 0.854 G 1.95 |
5. **Case 2, Missile Hit Probability Simulator (MHPS)**

Case 2 demonstrates a Missile Hit Probability Simulator (MHPS), revealing the uncertainty in the target’s position when the projectile is on its way towards the estimated hit point. This case is a good representation of military specific training. The creation of the Missile Hit Probability Simulator represents how parametric and phenomenal data were formulated by students. In this case, generic parameters are useful for detecting links between different phenomena. On the other hand, in training conditions, accurate data might be more valuable when one’s goal is to learn fighting tactics through repeated simulations.

The model is defined by the following main ideas:

- The target acquisition area is kept constant.
- The time between the target acquisition and the moment of impact can be selected.
- The user may set the movement factors of the target.
- The target has two different ways to react: it either continues using movement factors defined by the target acquisition or moves randomly between the time of the target acquisition and the moment of impact.
- Options when aiming at the target: shoot directly at the target or shoot towards a predefined goal defined by the target’s movement factors.
- The user is able to change the missile’s search area.
- The user is able to change the indication accuracy of the target.

The simulation starts from procedures where the centre of the missile acquisition area is set and where present parameters are either adjusted or accepted as they are. Then, once a sample target has been set, the simulator may start. For example, when a target ship is moving with a bearing of 250 degrees at a speed of 6 nautical miles, a generic subsonic missile has a speed of around 250 m/s and the starting distance to the target is set at 150 km, the time from launching the missile to the moment of impact is 10 minutes. The target may then move forward by one nautical mile during this time. However, it is also possible that the target changes its velocity and direction as it wishes while the missile travels towards it. So, in reality, the real target point for the missile is a random point inside the circle defined by the goal’s maximum velocity.

In our example above, the target acquisition area would be the circle that gets a radius of six nautical miles in ten minutes’ time. When the target varies its velocity randomly while still keeping its speed at
the maximum (6 nm/h), the missile hit accuracy is 8.3 % after 1000 test rounds. This result is based on whether the seeker in the missile is able or not to correct the final trajectory towards the target.

In order to extend the simulator’s usability, a specific user interface was created for Excel. The interface included a majority of the parameters seen in the real launching pad. Therefore, any user of the real system may practice with the missile hit probability simulator. In practice, a user loads the specific excel file and selects the main parameters and starts the simulation. In the interface, a graphical result picture is added to give a more informative view for the selected parameters. After each launch, the program shows either a hit or a miss.

6. Discussion of the simulation tool
Officers with little to no previous coding experience were able to create a working airplane flight simulator or a missile launch simulator (Cases 1&2). These two cases show how students can achieve their goals when they are allowed to do something that they consider useful and has a connection to their everyday life [22].

The simulation course itself showed that real life problems can be studied. Some of the results may be combined with relevant field tests. Solutions found in this course are not available through a “simple click” or by browsing the net. Moreover, quite many students have later on developed their tools in connection with their master’s degree studies.

In literature, the following aspects are mentioned as key advantages of VBA tools when linked to worksheet utilization:

- Familiarity. The use of a spreadsheet interface.
- Visibility of the data in worksheets.
- Portability. Requires an Office application (e.g. Excel). No need for any run-time license.
- Transparency. The follow-up of simulation: the data and generated output is accessible.
- Analysis. The user has complete control over the tool.
- Extendibility. Everything in the simulation is written to worksheets. This allows modular code. New modules can be linked to existing worksheets.

There are also disadvantages associated with using any unsophisticated tools for time-critical or graphically demanding tasks. For example, Excel with its VBA extension does not offer fast calculation or a sophisticated high architecture library structure. However, considering the reasons for VBA’s limitations, those are mainly irritations. Just to name one major limitation, Excel itself does not provide graphics, only graphs. [14]

7. Motivational aspects in course feedback
The original 5-step Likert scale is a psychometric scale that has 5 categories from which respondents choose one to represent their attitude, opinion, or even feelings about a particular issue. The standard student feedback at NDU consist of 21 statements. For discussion about this simulation course only 8 most meaningful aspects are shown in Table 2. When data are combined with qualitative data like open-ended questions, participant observation, and interviews, the survey’s validity is improved and its information becomes more concrete.

Those conclusions that are reached with instruments that gauge attitudes are only as good as the quality of the method. Even though items on these scales may have numbers assigned to each level of agreement, it cannot be assumed that these numbers represent equidistant units that can provide the interval-level data necessary for parametric statistical procedures. [23]

Open questions and further discussions with students point more to resources than contents or tools, e.g. the allocated working hours for the whole course could be more flexible. Overall, positive feedback for this course showed that students appreciate assignments which require inputs like creativity and deep concentration and which nevertheless connect their daily practice and duties.
Table 2. Student feedback in simulation course 8 most meaningful aspects out of 21 asked statements (N=10)

| NDU’s Standard questionnaire, Student evaluation of teaching | Average |
|-------------------------------------------------------------|---------|
| I achieved the goals set for the course                     | 3.9     |
| I was an active learner                                     | 3.9     |
| The instruction atmosphere supported learning               | 4.0     |
| Instructors mastered the facts                              | 4.5     |
| Overall grade for teachers                                  | 3.7     |
| The course produced new knowledge, and wasn’t just repetition| 4.6     |
| Assessment supported learning                               | 3.9     |
| Overall grade for the course as a whole (scale 1 to 5)      | 3.9     |

8. Conclusions

The simulation course gives guidelines on how to improve learning with the tool, but it is once again a question of personal interest how one wants to utilize the individual final part for professional development. It seems that the results that were achieved with this simulator course are realistic enough and therefore these results may be used in future military officer training.

Group work does not in itself necessarily mean better results or enhanced motivation. The ability to choose the best practices for each studying context requires a process of continuous evaluation. Guidance and clarity in teaching goals and applied tactics are needed. During any course continuous attention on achieved learning results (including intermediate ones) and motivational aspects may reveal hidden problems. This is especially true for individual homework, which would require customized practices that could truly improve student satisfaction. This simulation course presented here offers a very real linkage to the practical applications which are connected to the theory though simulations.

Student feedback revealed that this type of a simulation course was successful. Student’s feedback towards teaching methods has been positive during the years. Students have also learned simulation methods and used them later in their working life. Approach has been quite practical and modelling techniques oriented. Students have also improved their social skills by doing group works. This course however represents so called intensive courses and thus more emphasis should be given for preliminary preparations that support team work.

In the future we will increase new simulation tasks for our Master level officers. As an example the modelling of an explosion is taken for pondering. Simplified theoretical model on the subject that students will create will later be tested in practice in our becoming Virtual Reality video named “Inside of an Explosion”.

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