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Exploring the integration of CDIO, crowdsourcing and gamification into information security courses

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ABSTRACT: With the integration of technology into our lives and the availability of on-line sources, traditional teaching methods have been under scrutiny. Specifically, information security courses pose a challenge, because learning theory is not sufficient. These courses require students to develop hands-on skills and the use of tools that might cause serious damage if improperly used. The work reported here was to design and deliver a security course following CDIO (conceive, design, implement and operate) methodology. The course culminates in a *capture the flag* competition in a gamified crowdsourced way. The courses ran for three semesters and a survey was administered to gauge student satisfaction, perceived enjoyment and attitude (Likert scale questionnaire). The overwhelming majority of respondents, 71.4%, had positive feelings towards the courses; felt they made it easier to learn; found the laboratory experiments enjoyable and would consider enrolling in a similar course in the future. More interestingly, the majority reported the courses helped develop their collaboration (75.4%), communication and interpersonal skills (72.2%).

INTRODUCTION

As society heads into the third decade of the 21st Century, where Millennials are expected to dominate the workforce, considering how technology affects education becomes critical. Holding the attention of today's classes full of Generation Z students, who grew up connected and playing with smart phones and tablets, is ever more challenging. With both generations digitally savvy and spending one-third of their time on social media, the integration of technology into education is of the upmost importance [1]. Students are turning into shallow consumers of information, using the Internet as their extended memory; Googling everything, snapping photos, sharing assignments and instant messaging tips and solutions. Generation Z students feel special, expect instant gratification, and pleasurable experiences or they will simply disconnect and not engage in traditional classroom activities.

Narcissistic personality inventory (NPI) scores have been increasing significantly with the year of birth. This is fuelled by isolation stemming from technology [2]. While some believe that newer generations will suffer because of these changes [3], others see this as an opportunity to evolve our educational systems [4]. Education researchers call for major education reforms to present a more personalised and technologically appealing approach.

Technology is changing learning, and present educational systems must adapt to those changes. Using memory to retain information, deep-thinking and critical analysis of issues are giving way to the new habits of multitasking, skimming through brief information nuggets, sharing short social messages and looking for quick-fixes. Many consider these habits unhealthy and instead of multitasking they see fragmented time, short, unfocused bursts of thought, lack of mindfulness, and therefore less productivity [3]. Others argue that this represents new and shifting patterns of thinking. New sets of skills are being acquired, such as browsing, searching, skimming, quick thinking, filtering low quality information, and digesting vast amounts of data [5]. Therefore, academic environments must adjust to new modes of learning, more personal delivery and less stressful assessments.

As technology contributed to this *problem*, technology offers the solution [6]. Technology must be employed to advantage rather than panic over changes to human behaviour. Previous concerns about the industrial revolution or the media did not lead to the demise of, but the evolution of, civilisation [7]. With advancements in artificial intelligence, more tasks requiring human intelligence will be offloaded to computers. This should be viewed as a symbiotic integration of machines into our lives. Future generations will see this as how the world works and technology will be seen as an extension of capability, as opposed to a threat [8].

Educational systems must be reformed to accommodate these changes and apply these new skills and technologies to advantage. Change does not only mean the introduction of laptops, projectors, tablets and smartboards [5]. It includes teaching students, so as to maximise new skills and minimise the negative effects of modern technologies.

Course designers must recognise absence of mindfulness and be aware of technology as providing educational aids as opposed to cheating tools [9]. They must emphasise activities developing new skills of browsing, searching, filtering, sharing and digesting multiple information streams. An extremely good example of such learning activities is collaborative problem-solving, known as crowdsourcing. Crowdsourcing in education improves students' experience through co-operation in groups to solve problems. This makes search, post, tweet, snap, share and discuss hints and knowledge on-line, pervasive educational tools [10].

One particular course that might benefit from Internet collective intelligence would be ethical hacking. Information security courses are particularly challenging, because of the need to develop hands-on skills, master a large number of tools with seemingly endless command lines and the massive amounts of output data to analyse and synthesise [11].

The authors designed two courses with accompanying laboratories following the CDIO (conceive, design, implement and operate) methodology. The courses conclude with a gamified project allowing the students to work in teams that benefit from crowdsourcing. The project comprised a hacking competition, involving collaborating teams' competing to grab flags hidden inside an adversarial target machine. In this article, details are given of surveys of students, over three semesters, which measured their satisfaction, perceived enjoyment, attitudes and their feedback. The feedback asserts the success of integrating CDIO and gamification into security courses. The overwhelming majority of students had positive feelings toward the courses.

RELATED WORK

Many efforts have been made to reform traditional educational systems to incorporate modern technologies to improve knowledge delivery and the classroom experience [7]. Dziuban et al from the University of Central Florida studied the acceptance of blended learning in higher education among different generations [12]. Mature learners, baby boomers and generation X were the least satisfied in blended learning environments. Newer generations do not see the professor as holding open the doors to knowledge, nor do they see information limited to notes and library resources. They value one-to-one on-line interaction and asynchronous learning networks (ALNs), where they are self-taught seeking knowledge in unstructured ways, in their own leisure time and place [13]. They care less for general education courses as opposed to using the Internet to gain knowledge that translates into job skills [12]. In a study of libraries and learning spaces, Moore and Wells concluded that Millennials prefer *…face-to-face and online support,* as well as a *variety of collaborative and quiet study spaces* [14].

Numerous studies focused on engineering education and the need for new learning models. Noor explored the frontiers of aerospace engineering education enabled by technologies, such as 3D virtual and augmented reality simulations, smart devices, intelligent and autonomous vehicles. They explored learner-centred education (LCE) principles and presented methodologies for aerospace engineering education [15]. No evaluation or testing of their hypothesis or methodologies was implemented.

Schaefer et al was one of the earliest studies to spot the educational paradigm shift influenced by information becoming available through blogs, discussion forums, wikis, social media and videos on YouTube and others [16]. They argue for a new method of teaching future engineers, who could collaborate in a crowdsourced fashion with other engineers from different backgrounds to design new products. They designed a graduate course to teach the student how to learn skills related to professional engineering practices and become lifelong learners. They applied threshold concepts and transformational learning to a course of engineering design. They encouraged the students to imagine a 2030 design, and then led them in collaborative learning communities to come up with collective solutions for engineering design problems. Just 30 percent of the students were satisfied; the main drawbacks were the need to iteratively revisit the questions and the pressure of peer grading.

Svensson and Gunnarsson ran a CDIO design-build-test (DBT) electronics course over eight years [17]. Students worked in large groups of 10 to 25 to build microcontroller digital systems following the Linköping project management model (LIPS). The students worked in well-equipped laboratories with discussion, conference, component and server rooms. Continuous assessment of engineering skills was performed throughout all stages, from planning, design, management, and communication, to documentation and technical results. They relied on the university and student union evaluations systems to report scores for the course. No customised questionnaire was designed to measure the different aspects of the CDIO methodology and how it affected the course learning outcomes.

In 2017, Saparon et al proposed the project design education system (PDES), which was focused on soft skills for engineering project design courses [18]. Similar to CDIO, the approach included understanding, analysing and solving problems, while promoting collaboration and communication skills. There were three presentations and an evaluation of presentation skills. There was no discussion or evaluation of the effects on technical skills or effectiveness of collaboration and enjoyment of the learning experience. Crowdsourcing and gamification were not used.

Straub et al explored project-based learning for small spacecraft and proposed CubeSat development programmes be incorporated into university curricula [19][20]. Yong et al discussed applying CDIO to mechanical engineering capstone courses [21]. They focused on the technical implementation details and how to integrate CDIO into engineering design projects. None of the work surveyed was concerned with information technology courses nor was any concerned with information technology or security [22]. None simultaneously applied CDIO, gamification and crowdsourcing.

Traditional Chinese teacher-centred computer majors emphasise theory and disregard the importance of practical skills [23]. Even if there was an experimental component, it often involved following the instructor's manual. Therefore, there has been a considerable increase in the software talent gap between university outcomes and industry needs [24]. Lingling et al proposed a software teaching framework having CDIO project-based learning with emphasis on better laboratories, research, innovation and industry internships [25]. Bin and Shiming recognised the need for higher software quality and developed a student-centred software testing and verification course [26]. They integrated CDIO principles into the course. The course was composed of 35% theory, 15% experimental and 50% project. The assessments were diversified, and laboratories were equipped with modern tools to create occupational experience centres.

Both Lingling et al [25] and Bin and Shiming [26] reported improved software development and testing skills, and increased employability of their graduates. No scientific evaluation or evidence of their claims was presented! Jianfeng et al surveyed Chinese universities that had CDIO in higher engineering education and found graduates still lagging behind their counterparts in other developed countries. They argue for continuing efforts to reform engineering education [23].

Song et al integrated CDIO into a Web design course as a replacement for traditional engineering and information technology education methodologies [10]. They applied crowdsourcing and gamification to make the learning experience more engaging. The framework was tested in a seven-week university course with 269 students. The course was designed as a game with four stages, resembling CDIO stages. In each stage, the students had to complete individual or team tasks gaining skills for a particular career such as programmer or Web designer. Students who chose an exercise that they finished were recorded as having achieved the learning objectives! A final examination was given and marked at the end of the course, taking into consideration the stages the students had completed.

The questionnaire reported 72% satisfaction and a 19% increase in the number of students who scored over 80%. However, the students' engagement varied, being low in stages 1 and 4, while increasing in stages 2 and 3. Only 35.7% finished all four stages of the course and engagement dropped significantly in the last stage before the final examination.

CDIO INFORMATION SECURITY COURSES

Modern university courses may include collaborative education, flipped learning, blended learning and formative assessments. In collaborative education, students work in groups to develop solutions to problems. Flipped classes are more learner-centred with appropriate handouts, on-line and laboratory exercises to supplement theory classes. Blended learning combines traditional class material with on-line resources, such as videos, animations, software tools, on-line search, group assignments, on-line quizzes and instant on-line feedback apps [27].

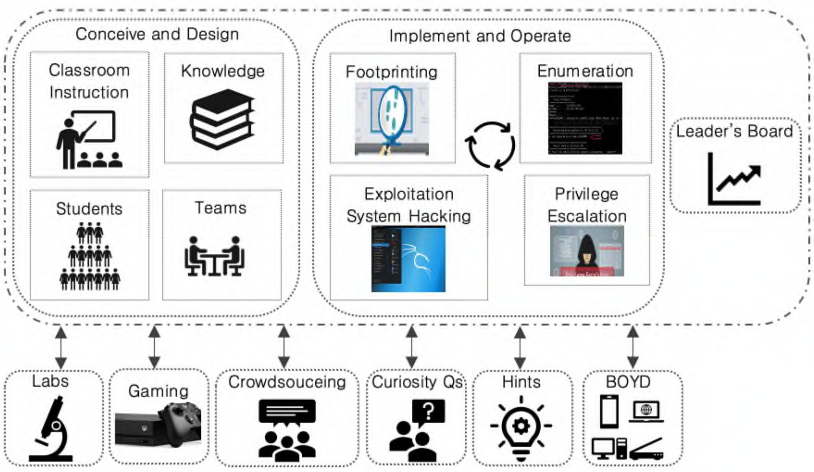

Figure 1: CDIO, crowdsourcing and gamification framework.

Conceive, design, implement and operate is an educational model designed for engineering courses that mimics the product design lifecycle. There is an analogy between the engineering lifecycle and the ethical hacking course learning activities. Students work in teams to learn information security and ethical hacking best practices. Figure 1 shows the CDIO framework for the ethical hacking course that iterates through the following stages.

1. Capacity building and project definition represents the conceive stage of CDIO, C. In this stage the students are introduced to the course plan, hacking tools and gamified project. The students form teams and establish

connections with classmates. They are taught hacking tools and skills through short laboratory exercises. By the end of the stage, the students have enough skills to perform short hacking tasks [28]. Yet they have no definite plan or complete approach to hack a system from scratch.

2. Project planning represents the design stage of CDIO, D. In this stage the students start to *connect the dots* and formulate a plan on how to approach a vulnerable machine through most of the steps of the hacking process: reconnaissance, enumeration, exploitation, system hacking and privilege escalation. The students experiment with their design, to perfect it [29].

3. The implementation phase I of CDIO takes place throughout the semester with guided gamified hacking exercises of simple machines. This is an instructor-led hacking and informal competition, where teams apply the skills learned and design developed in stages C and D, to hack specially tailored machines. The machines are designed to teach certain attack vectors [30]. Four machines are used:

    a. *Tr0ll* teaches the students basic web hacking, on-line password cracking, basic exploitation and system hacking.
    b. *BasicPentesting2* teaches target discovery, enumeration, vulnerability scanning and SSH (Secure Shell) exploitation.
    c. *Sedna* teaches target identification, enumeration and ports access, advanced Web server hacking, Metasploit framework console (Msfconsole), Msfvenom, exploitation, system hacking, privilege escalation and rooting target machines.
    d. *Seattle* teaches database hacking, SQLmap, Burp Suite and decryption [31].

4. Capture the flag competition (CTF) final project represents the operate CDIO stage, O. The students test their acquired knowledge, skills, plans, design and operate in a collaborative fashion to hack a boot to root machine. The machine is carefully designed to test hacking skills and introduce new and unknown challenges. Overall, there were 10 flags (text files) carefully hidden at different locations throughout the machine. Six simple flags, worth 10 points each, should be grabbed by the majority of the teams. The next two flags are more challenging, requiring system access and are worth 20 points each. Finally, the last *root* flag is worth 30 points. The CTF is a fun game with a leader's board showing teams and their progress.

During the I and O stages, intra- and inter-team collaboration was encouraged, without compromising the sanctity of the project. This crowdsourcing learning approach helped teams collaboratively solve problems and share knowledge, where low achievers learn from their peers. In addition, less effort was needed by the instructors. Throughout all the phases Internet collective intelligence was permitted and encouraged.

Ethical hackers often refer to system help and on-line forums for assistance with command syntax, connectivity, access problems, and so on. Gamification made the class fun, engaging and challenging. The students were keen to get onto the leader's board and felt proud of their progress. The framework encourages bring your own device (BYOD) that allows the students to use their personal devices, fostering more engagement and personalisation. To promote creativity and maintain engagement, face-to-face and on-line assistance are available.

Tips, hints and curiosity questions were employed to lead the students during training with the four training machines [32]. Tips may be offered at the expense of points taken off the grabbed flag.

Flipped, blended learning and technology was employed to enhance the overall experience. Each team had access to group and class level Wikis, blogs and chatrooms. Furthermore, the target virtual machine was bridged to allow after-hours access.

A mix of formative assessments and diagnostics testing help to identify weaknesses and customise delivery to the students' needs. Teams were allowed to submit multiple laboratory reports, and the instructors pointed out tips and missing parts to improve the grades. One short test and one mid-term examination were given to assess the knowledge and learning outcomes. There was no final examination and the final project constituted 40 percent of the final grade.

RESEARCH METHODOLOGY

The approach to this research followed a positivism research paradigm since knowledge could be gained through observation and measurement. In other words, the research findings are based on observations quantified by collecting data and by interpretation. To achieve the research objective, the researchers followed a quantitative method to answer the research questions. In sequence, the data were gathered by questionnaire, checked for analysis, and then a descriptive quantitative data analysis performed. Phase details are presented in the following subsections.

Instrument Development

The researchers developed a questionnaire instrument based on the CDIO and education literature. The questionnaire contained four main sections: demographics (age, gender, nationality and educational level); research items starting with categorical questions about the course syllabus; laboratory structure; course delivery and grading criteria. The third section described teaching approaches; CDIO (mastery of concepts, design, implement and operate in the laboratory); resources and administration; demonstration; interpersonal skills (teamwork); technical skills (curiosity); perceived enjoyment; attitude towards the course; behavioural intention; and, finally, assessment of the overall experience and evaluation.

A five-point Likert scale was applied to measurement of the responses (scores ranged from 1 = strongly disagree to 5 = strongly agree, with the neutral score = 3). The survey was available in English (English is the medium of instruction at Zayed University). The survey instrument was refined during a pre-test by employing three faculty members from the IT college to ensure validity. Very few items were rephrased. Finally, the last part of the survey provided one open-ended question for any suggestions regarding employing CDIO in future laboratories.

Data Collection and Preparation

Research data were gathered by following the convenience sampling approach. Convenience sampling is based on a non-random sample, where a margin of error cannot be computed, and the results are not projectable to any population other than that of the specific sample. On-line self-administered surveys were sent through invitation links to survey students' experience and perceptions.

Six laboratory classes at the College of Technological Innovation (CTI) employed CDIO at Zayed University on two campuses (Abu Dhabi and Dubai). In total, 126 senior students agreed to take the survey within three months. Then, the data were downloaded from the google.com/forms portal. All students' responses were completed. All responses were valid and eligible for analysis.

FINDINGS AND ANALYSIS

The survey results were based on a non-random, opt-in, on-line sample of 126 information security students in the CTI at Zayed University. Since the data are based on a non-random sample, a margin of error cannot be computed and, as stated above, the results are not projectable to any population other than the specific sample. Because of space considerations, the authors cannot include here all results from the experiment. However, included are the results of mastery of concepts and design, implement and operate in the laboratory, teamwork, curiosity and students' overall experience.

To evaluate the efficacy of the CDIO methodology, the authors measured the mastery of the concept, design, implement and operate in the laboratory. Respondents (80.2%) thought the instructor explained very well the design and usage of different security instruments; and 81% thought the laboratory experiments improved their understanding of different security instruments. In addition, 78.6% agreed that the experiments are related to the learning outcomes and 74.6% agreed that the implement and operate phases helped them improve their coursework.

Figure 2 shows the attitude towards the course, with 71.4% thinking it was worthwhile. Moreover, 72.2% felt positive towards laboratory experiments and 63.5% would like other courses to have similar laboratory setups. The authors also measured the behavioural intention and 73% would recommend this course to a fellow student. The overall experiment was successful and 73% of the students felt the course made it easy to learn through the laboratory experiments. The most striking part of the evaluation was teamwork and interpersonal skills. Figure 3 shows that 75.4% of the students reported the courses helped develop their collaboration and 72.2% thought it helped in their communication and interpersonal skills.

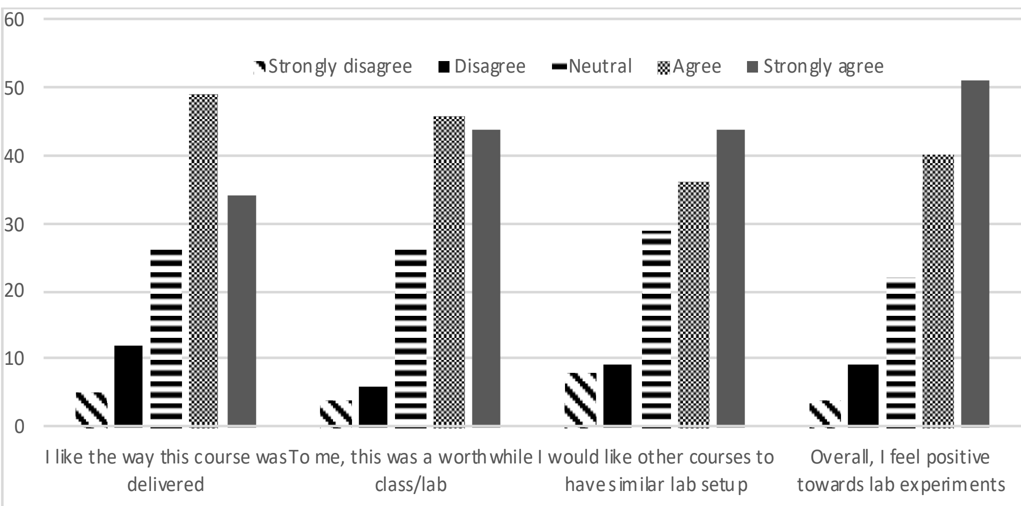

Figure 2: Attitudes towards the course.

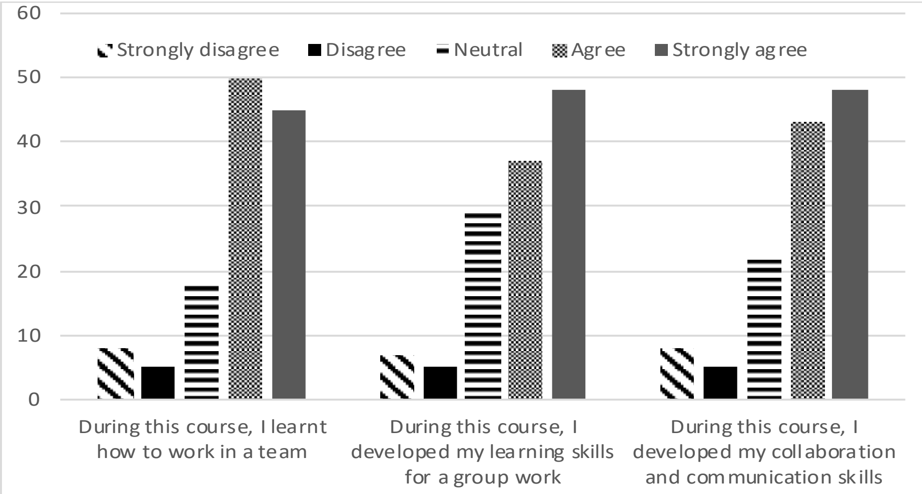

Figure 3: Teamwork and interpersonal skills.

CONCLUSIONS

A CDIO framework developed and proposed for information security courses was discussed in this article. Gamification, crowdsourcing and blended learning were applied to make learning more fun. From development of the proposed framework it was found that experience is the best teacher.

Evaluation was by means of a questionnaire instrument based on a non-random, opt-in, on-line sample of 126 information security students. The CDIO project-based implementation with integration of crowdsourcing and gamification into the ethical hacking course was shown to be a success. Future research work may test other constructs with correlation and regression testing.

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