HOW (WELL) ARE WE ASSISTING OUR STUDENTS IN BECOMING 21ST CENTURY STEM GRADUATES?

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Abstract
Contemporary global economies heavily rely on human capability to acquire new knowledge, foster innovation and promote scientific development. This requires acquisition and development of specific skills to allow modern graduates to become agile and effective employees, capable of leading and sustaining progress.
Our research investigated to what extent we are preparing our students for these roles, in the context of a first-year Computational Science unit, by assisting them in becoming discipline experts and expert learners at the same time. More precisely, we formulated the following research questions: to what extent did we assist students in acquiring and developing their 21st Century skills by 1) promoting students' *engagement,* and 2) assisting students in becoming *expert* learners? To answer to these questions, first the crucial, 21st Century skills as defined by industry were identified and mapped against learning outcomes of the unit under investigation. Next, student engagement and the level of their expertise in the learning process were investigated through a unit evaluation survey. Data analysis shed light on factors influencing student engagement within the designed learning environment and the associated development of expert learning skills. A further outcome of this pilot study was to identify the need for further in-depth research with larger sample sizes into the research questions posed.

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INTRODUCTION
Today's economic and social developments heavily depend on advances in knowledge. The way society promotes acquisition of knowledge, organises knowledge systems and ensures continued intellectual and scientific progress conditions its long-run economic growth (Lafond, 2015) and ensures high status on the global arena. Contemporary post-industrial economies are often described as knowledge-based economies. Their cornerstones are 'production and services based on knowledge-intensive activities that contribute to an accelerated pace of technological and scientific advance as well as equally rapid obsolescence' (Powell and Snellman, 2004, p. 201).

Contemporary higher education (HE) institutions are facing the challenge of how to equip modern graduates with skills allowing them not only to adapt to the needs of the economy, but also to provide them with strategies for lifelong learning, hence enabling intellectual growth, innovation and continued advancement of knowledge. The above-mentioned challenge can be successfully addressed through collaborative effort of industry and educational institutions. Industry's responsibility lies with a clear description of the expectations with regard to contemporary graduates, while higher education institutions' responsibility is to ensure that these expectations can be satisfied by assisting their graduates with acquisition and development of a specific set of skills, commonly known as 21st Century skills. The question is – how effectively are we teaching the above-mentioned skills to assist future graduates in becoming versatile, 21st Century employees?

LITERATURE REVIEW
For quite some time industry has expressed concerns about the inadequate preparedness of graduates for the above-mentioned particular challenges of modern economies (McGaw, 2013). In 2009, Cisco, Intel and Microsoft, alarmed by this lack of preparedness in graduates, funded research to identify, define and develop methods for measuring these skills and competencies which were judged crucial to industry but lacking in the average graduate (Griffin and Care, 2014, McGaw 2013). The ATC21S™ Project developed a model encompassing four sets of specific 21st century skills, all 'underpinned by a set of knowledge, skills, attitudes, values and ethics' (Griffin and Care, 2014, p. 7). As a result, the following 21st Century skills were identified (Griffin and Care 2014, p 7).

Table 1: 21st Century skills, as identified by ATC21S™ Project

Ways of thinking	Ways of working	Tools for working	Living in the world
▪ Creativity and Innovation ▪ Critical thinking, problem-solving and decision-making ▪ Learning to learn and metacognition	▪ Communication ▪ Collaboration and teamwork	▪ Information literacy ▪ ICT literacy	▪ Citizenship - global and local ▪ Life and career ▪ Personal responsibility ▪ Social responsibility

We make two observations regarding this framework. First, the framework categorises in four groups various skills and abilities, all requiring appropriate levels of achievement in remembering and understanding. Indeed, these foundational levels of cognition (Krathwohl, 2002) are pre-conditions for acquisition and development of the above-mentioned skills and capabilities. Second, development of skills necessitates facilitation – they need to be taught and learned. Therefore, acquisition of 21st Century skills requires development of a double expertise: knowing the discipline content and knowing how to learn. This means that a successful, flexible graduate should be a *content* expert as much as an *expert* learner.

Our team, composed of specialists from mathematics and education, investigated how and to what extent we are assisting our students in acquiring the above-mentioned attributes of a 21st Century graduate, in the context of a first year Computational Science unit offered at a large, metropolitan university. To this end we formulated the following research questions: to what extent did we assist students in acquiring and developing their 21st Century skills by 1) promoting students' *engagement,* and 2) assisting students in becoming *expert* learners?

We argue that the investigation of student engagement allows us to identify the relationships between engagement, satisfaction and learners' progression in learning – both discipline content and principles of learning (learning how to learn). Therefore, two educational constructs necessitate definition: student engagement and expert learner. Despite growing research investigating student engagement in higher education, this complex construct still remains 'weakly theorised' (Kahn, 2014, p. 1005). For the purposes of the current research, we define student engagement as a 'contribution that students make towards their learning, as with their time, commitment and resources' (Kahn, 2014, p. 1005). As for the construct of expert learner, we will adopt the definition developed by leading researchers in Universal Design for Learning (UDL), of an expert learner as 'strategic, resourceful, and motivated' (Meyer, Rose and Gordon, 2014). This educational framework intends to assist all learners with mastering the learning process and becoming expert learners. We note that the definitions of student engagement and expert learner are to some extent complementary as they both imply behavioural, cognitive and affective engagement in learning.

RESEARCH CONTEXT

The unit under investigation was offered in Semester 2 of 2015 and aimed to provide students with a practical understanding of computer-based solutions to scientific problems from a wide range of interdisciplinary application areas. The unit was offered as a university-wide elective and attracted a diverse cohort of students, from STEM-related disciplines (i.e. Science, Information Technology, Engineering and Mathematics), but also Business, Education and University Exchange Programs. This introductory-level unit introduced the mathematical software package *MATLAB* as a tool for processing and analysing data (e.g. spatial, image, sound) as well as conducting some introductory simulations (e.g. random walks, cellular automata).

The learning environment included lectures, workshops and practicals (the latter two being computer-based), set up to ensure learning flow between these constituents as discussed below. By making the learning flow tight and clearly visible to students, the design of the unit focused on two goals. First, the unit assisted students with (co-)construction of knowledge through multiple opportunities for recall and exposure to new concepts embedded in the design. Second, it applied the principles of active learning by 'simulating' experience in real-world computational science. That is, students were provided with the opportunity to learn through experience and in collaboration with more advanced peers (teaching team members, fellow students) during hands-on, computer-based practicals. Opportunity for autonomous learning in the sense of multiple possibilities to acquire, apply, evaluate and create new knowledge was created through lectures (acquisition of new knowledge) and workshops (application, evaluation and creation of new knowledge).

LEARNING ENVIRONMENT

Lectures

Focused on knowledge transmission and delivered in a didactic way, one-hour weekly lectures were devoted to discussion of the week's topic, development of background knowledge and demonstration of some concepts in *MATLAB*. From a UDL point of view, lectures were intended to support students' co-construction of new knowledge by engaging with content provided by lecturer.

Workshops

The workshops (each one hour) followed directly from the lectures, built on the theoretical background and provided students with the opportunity to apply lecture content to learning and practising the new techniques they needed for that particular week. This component promoted autonomous learning through a set of activities to be solved using individual worksheets specifically designed for each week. Although focused on self-study, discussion and collaboration were encouraged and students were assisted by a member of the teaching team. The activities completed during the workshop constituted the background for students' development of essential skills for the practicals. In this way, learning flow between the workshop and the practicals was strengthened.

Practicals

Team-based two-hour practicals, timetabled for the following week, required prior completion of the 'homework' (workshop activities) and were focused on solving contextualised, discipline-specific 'real world' problems in collaborative, multidisciplinary teams. This part was aimed at enabling learners to recall and apply previously acquired knowledge in order to develop computer-based solutions to problems through collaborative activities.

RESEARCH METHODOLOGY

Mixed research methods (quantitative and qualitative) were used to collect and analyse data relevant to our research questions. In particular, to answer the first research question, the team identified the 21st Century skills and capabilities through literature review and by direct comparison mapped these against the Unit learning outcomes.

In Week 11 of the 13-week semester, students were invited to fill in an online, anonymous survey which remained open for five weeks. Its purpose was to determine students' engagement with the constituents of the unit and with the content knowledge. To investigate students' engagement, a set of questions enquired about students' perceptions of and engagement with educational and social affordances for learning through lectures, workshops and practicals. The last series of questions of the survey investigated whether students perceived and took the opportunity of becoming expert learners. The survey was administered via Survey Monkey and used a combination of structured questions (i.e. Likert-scale, open/closed) and questions inviting open comments.

Additional data were also collected from two student-evaluation-of-unit surveys administered by the university, one at mid-semester and one at end-of-semester. These surveys focused on students' overall perceptions of the learning opportunities afforded to them and their satisfaction with the unit.

FINDINGS AND DISCUSSION

Unit design

Mapping of the 21st century skills against the unit's Learning Outcomes is shown in Table 2 below.

Table 2: Mapping of 21st century skills against the unit's Learning Outcomes

Unit Learning Outcomes	21st Century skills
Demonstrate knowledge of and apply programming skills to implement modelling and problem-solving solutions from a range of scientific application areas.	✓ creativity and innovation ✓critical thinking ✓ problem-solving and decision making ✓ information literacy ✓ ICT literacy
Apply computational techniques for simulation and modelling, generate output data, and apply analytical and/or visualisation skills to interpret that data.	✓ creativity and innovation ✓critical thinking ✓ problem-solving and decision making ✓ information literacy ✓ ICT literacy
Demonstrate knowledge of a range of raw and processed data formats, and demonstrate the skills to investigate such data.	✓ creativity and innovation ✓ critical thinking ✓ problem-solving and decision making ✓ information literacy ✓ ICT literacy
Work independently and as an effective member of a team.	✓ communication ✓ collaboration and teamwork

We make two conclusions from this mapping process. First, teaching of most of the 21st Century skills was explicit in unit Learning Outcomes. The mapped 21st Century skills and capabilities shown in the table were addressed through the practical activities occurring during workshops and practicals and the theoretical background presented during lectures.

Second, the skills not included in the unit Learning Outcomes were either out of the scope of this first-year computational science unit (living in the world) or their teaching was to some extent implicit in the approaches to teaching and learning applied in the unit (learning how to learn, metacognition), as opposed to being explicitly stated in the Unit Outline. We hypothesise that through the unit design emphasising co-construction of knowledge and active learning within a cohesive learning flow, we have created the opportunities for students to acquire and develop their expertise as learners without explicitly teaching this particular set of skills.

Student engagement

21 of 115 students filled in the online survey, constituting an 18% response rate. Recognising the low response rate, we emphasise that this is an indicative study, with the objective of identifying need and providing background for further research. We also note that two further data collection instruments were available to the researchers, in the form of the unit evaluation surveys run by the university. These surveys had response rates of 23% and 36%, and indicated high student satisfaction with learning opportunities and the unit overall, with all ratings at 4.4 or higher on a 5-point scale. These results serve to validate the more detailed data obtained from the online survey, to be described next.

The data collected and presented below indicate positive student engagement with the various constituents of the created learning environment. They provide evidence of students' satisfaction with features of the unit design, including delivery modes, teaching approaches, tasks and assessment. We make two observations here. First, the data are consistent with the level of student satisfaction indicated by the university surveys. Second, it is important to note that positive satisfaction indicates higher level of engagement, one of the factors directly impacting students' learning. Thus we conclude that the evidence of student satisfaction is an indirect indication of acquisition and development of unit learning outcomes, which contain most of identified 21st century skills and capabilities.

Table 3 shows students were satisfied with the learning environment, with all respondents stating they could see clear connections between lectures, workshops and practicals.

Table 3: Overall satisfaction with the designed learning environment (n=21)

Question	Always	Most of the time	Sometimes	Sporadically	Never
I could see clear connections between lectures, workshops and practicals	85% (18)	14% (3)	0	0	0

Responses to the survey structured questions on perceptions of educational and social affordances for engagement are shown in Table 4 below.

Table 4: Educational and social engagement

	Always	Most of the time	Sometimes	Sporadically	Never
Lectures were taught in the way that allowed me to engage with:					
a. the unit material	61% (13)	28% (6)	0	4% (1)	4% (1)
b. my peers	19% (4)	23% (5)	38% (8)	9% (2)	9% (2)
c. the teaching team	52% (11)	9% (2)	33% (7)	0	4% (1)
Workshops were taught in the way that allowed me to engage with:					
a. the unit material	71% (15)	19% (4)	4% (1)	0	4% (1)
b. my peers	23% (5)	19% (4)	28% (6)	14% (3)	14% (3)
c. the teaching team	52% (11)	19% (4)	14% (3)	4% (1)	9% (2)
Practicals were taught in the way that allowed me to engage with:					
a. the unit material	76% (16)	23% (5)	0	0	0
b. my peers	80% (17)	9% (2)	4% (1)	4% (1)	0
c. the teaching team	57% (12)	28% (6)	14% (3)	0	0

The data show that the overwhelming majority of students engaged with the material, suggesting that opportunities for (co-)constructing knowledge through individual and collaborative activities were perceived by students and taken up. Around 90% or more of respondents perceived that all three delivery modes always or mostly allowed them to engage with unit material. We emphasise once again that we see student satisfaction as a factor impacting on student engagement, an important element influencing acquisition and learning. The ways students engaged with peers reflected the unit design: while lectures were didactic and workshops encouraged individual learning, practicals required students to work in collaboration. At least 85% of respondents thought that practicals always or mostly allowed them to engage with peers and the teaching team, showing that these activities achieved that aim of their design. From this evidence, the design of the practicals can be argued to allow learning of the activity-relevant 21st Century skills of teamwork and communication.

From this data we hypothesise that the learning environment motivated students to actively engage with knowledge and seek opportunities for acquiring new knowledge through collaboration with more advanced peers. Vygotsky's concept of Zone of Proximal Development (1978) describes the conditions for optimal learning, when the constituents of the created environment support motivation for learning. Students' responses presented above might suggest that this particular environment provided favourable conditions for learning, with students willing to make cognitive effort (engagement with material), intellectual effort (strategic planning and execution of planned actions), as well as affective effort (engagement with more advanced peers).

Expert learners

Table 5 below summarises responses to the structured survey questions on perceptions and take-up of opportunities to become expert learners. The data indicate that respondents, motivated to learn, were adopting strategic attitudes towards their own learning. The majority of respondents reported at least sometimes using previous knowledge in new contexts. Such a strategy might be considered as a sign of (deep) engagement with knowledge resulting in successful construction of new knowledge to be retrieved and applied in new environments. Based on this observation we conclude that students' responses provided evidence of strategic, resourceful and motivated learning (i.e. making conscious choices regarding alternative help, and willing to seek alternative help). In short, the data suggest that some respondents were on their way to becoming autonomous, expert learners, demonstrating an active attitude in searching for and consulting alternative resources.

Table 5: Students as expert learners (n=21)

Question	Always	Most of the time	Sometimes	Sporadically	Never
I used previously acquired knowledge to understand the new content I was learning.	33% (7)	42% (9)	23% (5)	0	0
If I did not understand something, I would actively seek alternative help outside the provided materials, such as:					
a) watching online tutorials available on You Tube or other platforms I found myself	14% (3)	19% (4)	19% (4)	23% (5)	23% (5)
b) using alternative notes/ readings/ textbooks I found myself	19% (4)	19% (4)	19% (4)	23% (5)	19% (4)
c) asking the teaching team	47% (10)	28% (6)	19% (4)	4% (1)	0
d) asking my peers	28% (6)	38% (8)	23% (5)	4% (1)	4% (1)

The most common responses to statements (a) and (b) were that students only sporadically or never searched for additional help from online or alternative text sources. Almost half of respondents only sporadically or never sought help from what might be considered 21st Century resources of online material. The free-response comments help clarify the diversity in student help-seeking strategies. One student wrote: 'I found the provided materials were enough to learn and get through the content', while another stated: 'I never had to use alternate resources because my peers and teaching team helped me enough'. Although providing different reasons, both comments demonstrate that learners perceived the opportunity for learning, and therefore they took conscious (strategic) decisions to use only resources already available to them. The responses to statements (c) and (d) about asking the teaching team and peers confirm this. Here the most frequent responses were to always or mostly ask the relevant people around them in the learning environment.

Being an 'expert learner' also means being capable of applying acquired knowledge in new contexts. When asked if they have already used some of the learned techniques in other contexts, eight students (38% of the sample) provided examples of having done so (in contexts of engineering, chemistry and IT). Some students also mentioned helping their peers from other disciplines. One student wrote: 'I plan to use some of these techniques in the classroom when I am teaching. I think high school students would really appreciate learning mathematics through this sort of technology at a school level. It's much more engaging and useful'. In summary, the data suggest that the model did enable, at least to some extent, students' engagement, self-reliance and resourcefulness.

CONCLUSION

To prepare graduates for the challenges of modern knowledge-based economies, contemporary higher education institutions need to assist students with acquisition and development of 21st Century skills. We argued that this can be achieved by helping learners in becoming double experts: in content and in learning process. We mapped these 21st Century skills to the Learning Outcomes of a first year Computational Science unit, finding that the unit develops many of the identified 21st Century skills.

We collected and analysed data to find out whether students engaged with the unit, and hence at least initiated the acquisition of the double expertise conducive to development of 21st Century skills.

Based on the data collected and its analysis, we conclude that at least some students were on their way to becoming expert learners: developing the necessary skills of being strategic, resourceful and motivated learners. As for remaining 21st Century skills and capabilities, we conclude that the unit under investigation did provide opportunities for learners to acquire and develop the above-mentioned skills and capabilities, however in an indirect way.

More precisely, evidence was gained that students generally successfully engaged with unit material and understood new content. The data show that the learning environment was effective in engaging students at cognitive, strategic and affective levels. As for expertise in learning, opportunities for acquiring and developing these skills were implicitly embedded in the educational environment created. The data indicate some students did perceive opportunities for self-learning and proactively searched for alternative resources. We hypothesise that the stimuli for self-learning implicitly included in the unit design were effective in assisting students in developing lifelong learning skills.

We recognise the need for further study to investigate the following questions: 1) Should learning to learn and metacognition be explicitly taught in STEM-focused disciplines? 2) If yes, what pedagogical approaches should be used? 3) How can effective and efficient learning experiences be designed to actively support modern students to become agile employees and expert, lifelong learners?

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