THE TWENTE EDUCATIONAL MODEL IN THEORY AND PRACTICE: TWO MODULES AS EXEMPLARS

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ABSTRACT

Teaching for an unknown future in rapidly changing times is a challenge with which all educators grapple, not least amongst them engineering educators. The University of Twente's eponymous educational model addresses this challenge, reflecting their “High Tech - Human Touch” motto by blending the technical needs of the degree with current research in engineering education. In this paper I will present and describe the Twente Educational Model. As illustration of the model in practice I present two exemplar modules in the departments of Advanced Technology and Electrical Engineering. While challenges to the model remain, it represents a mature model of curriculum reform involving project-based learning and adds to the literature on successful engineering education reform.

INTRODUCTION

Educating university students in a rapidly changing world is a widely discussed challenge recognised globally (Graham, 2012; Graham, 2018; Belski, Adunka and Mayer, 2016). Approaches related to meeting this challenge employ a variety of descriptive terms, amongst them future-proofing education (Meijers and den Brok, 2013; Cornejo, O'Hara, Tarazona-Vasquez, Barrios and Power, 2018), teaching 21st century skills (Jang, 2016), or teaching for an unknown or uncertain future (Barnett, 2004; Stein, 2017). In engineering, teaching disciplinary skills alone may once have been sufficient to prepare a graduate for the workplace (although perhaps it never was altogether), but certainly today there is increased need for transferable skills such as communication, problem solving and project management (King, Varsavsky, Belward and Matthews, 2017; Jollands, Jolly and Molyneaux, 2012), as well as an orientation towards lifelong learning (Graham, 2012; Cornejo et al., 2018).

Graham, in her 2012 report on successful curriculum change to address 21st century challenges, observes that successful engineering education change almost without exception involves an interconnected and redesigned curriculum. In order to take a course or programme that was once taught traditionally and to change it to meet the needs of the student of today, it is not enough to simply manipulate content such as updating the topics or to add non-technical skills on top of the existing technical programme (Graham, 2012; Edström and Kolmos, 2014). Fundamental curriculum-wide change is needed. One such frequently adopted change by current and emerging leaders in engineering education (Graham, 2018) is towards a curriculum driven by project-based learning (PBL). Project-based learning, alternately project-led education (Centre of Expertise in Learning and Teaching, 2017), in essence involves having projects be the platform for students to develop process skills such as project management, self-directed learning, communication and collaboration as well as the traditional technical and disciplinary skills and knowledge. Projects can further allow for analysis and identification of problems in addition to problem solving itself (Edström and

Kolmos, 2014). PBL, done well, is recognised as a form of teaching and learning preparing students well for the workplace. For instance, Edström and Kolmos (2014) cite research indicating that employers value graduates who have been through a PBL curriculum highly, saying that they can work "from day one" (p. 542), are motivated and have well developed skills. Jollands et al. (2012) in their study comparing the work readiness of PBL and non-PBL graduates find that certain skills are equivalently developed through project-based learning as through the vacation work of non-PBL graduates, however their research suggests that communication skills and the ability to systematically apply engineering knowledge in design are better developed through a PBL curriculum than through a traditional programme with vacation work.

There is no single definition of project-based learning on which everyone agrees, however there are broad principles which focus on the teaching and learning process. Edström and Kolmos (2014) suggest three principles underpinning effective project-based learning, namely (1) an orientation towards defining and analysing problems, (2) interdisciplinary curriculum content and (3) a social approach to learning. Edström and Kolmos's third principle, that of a social approach to learning, resonates with Schoenfeld's (1992) view of thinking mathematically. Mathematics is "an act of sense-making that is socially constructed and socially transmitted" (p. 339) and "classroom mathematics must mirror this sense of mathematics as a sense-making activity, if students are to come to understand and use mathematics in meaningful ways" (pp. 339-340). Project-based learning provides links between classroom mathematics and real world applications, encouraging intrinsic motivation to master the work as well as developing the skill of thinking mathematically (and as an engineer) through active sense making. The philosophy behind PBL therefore places as much value on how students learn than on what students learn. Recognising the need for curriculum change to address the challenges of a rapidly changing world, changes that perhaps a technical university is particularly well positioned to carry out, in 2013 the University of Twente (UT) in the Netherlands rolled out an innovative institution-wide curriculum with project-based learning in thematic modules at its core.

THE TWENTE EDUCATIONAL MODEL

The undergraduate curriculum at the University of Twente was redesigned in the period 2010-2013 and the design was rolled out across all faculties in September 2013. The redesigned curriculum hoped to sustain and renew the university's profile as an entrepreneurial university developing sustainable solutions to societal problems, increase student retention, and improve the educational offerings through research-driven innovations (CELT, 2017; Visscher-Voerman and Muller, 2017; Warmerdam, 2017). The drivers behind the redesign of the curriculum have been discussed elsewhere (Visscher-Voerman and Muller, 2017; ter Braack, Rouwenhorst and Slotman, 2015; Bollen, van der Meij, Leemkuil and McKenney, 2015; Venner, 2018; van den Berg, Steens and Oude Alink, 2015); now in 2019 the Twente Educational Model (TEM) has matured and is understood to have two primary foci.

The first focus of TEM is the incorporation of interdisciplinarity into the undergraduate curriculum. The University of Twente, as a technical research and entrepreneurial university, engages in interdisciplinary research. By clustering undergraduate studies in modules designed to integrate disciplinary units with a common interest in a central project, TEM seeks to reflect the interdisciplinary nature of the institution's research in the classroom (Damgrave and Lutters, 2016). The educational model is designed to avoid the "silo" effect, which creates apparent barriers between disciplines, barriers which are not there in research nor in the technical careers the students may follow (CELT, 2017).

The second focus of TEM is the challenge of teaching and learning in a rapidly changing world. Society and its demands of graduates change fast. Many careers, including within the field of engineering, exist today which did not exist twenty years ago and it is reasonable to assume that the same will be true of twenty years in the future (Belski et al., 2016; CELT, 2017). What TEM hopes to achieve is to provide students with the opportunities to develop skills as communicative problem solvers who can respond to rapid change and continue to learn (ter Braack et al., 2015). The value of a technical degree is strengthened by well-developed skills in organisation and communication (CELT, 2017). The influences on TEM therefore derive from the technical world of interdisciplinary research and industry as well as from the world of educational and social science research related to transferable non-technical skills.

The undergraduate programme is designed as a series of (potentially interrelated) modules, each with a theme. Each module lasts one quarter, so a three year degree is comprised of twelve modules, as shown in Figure 1. At the core of each module is a team project; as far as is possible the project is based on something in the real world, “an activity that challenges students to independently gain knowledge and skills” (CELT, 2017, p. 7). The rest of the module consists of units that (ideally) cohere with one another as well as with the project. An example is the first module in the department of Advanced Technology where projects related to dynamic systems (roller coaster design, for instance) are at the core of the module, supported by units (sometimes called courses) in calculus, mechanics and laboratory practice. Knowledge and skills offered in the module’s units are all necessary for successful completion of the project and success at all the parts of the module are necessary for a passing grade for the module. The projects are designed to be appealing and thereby create an intrinsic interest in developing the necessary skills (see also Cornejo et al., 2018). The ideal pedagogic context is one of student-centred teaching and active learning (CELT, 2017; Venner, 2018; Damgrave and Lutters, 2016).

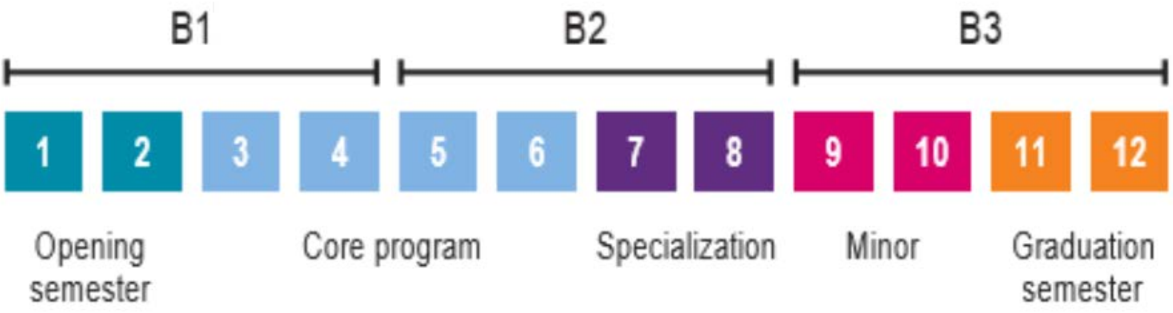

Figure 1: Module structure within Bachelor’s Programme
Figure source: Visscher-Voerman and Muller, 2017. Reproduced with permission.

The interrelated system of the projects and the supporting units is in line with the interdisciplinary aim of TEM, while the roles the students are called upon to play in their project teams speak to the aim of producing graduates who are flexible problem solvers. Within the teams, students are expected to take on multiple roles, specifically researcher, designer and organiser (CELT, 2017; Visscher-Voerman and Muller, 2017; ter Braack et al.2015). Not only does taking on these roles help develop the corresponding skills, but it allows students to follow their own specific interests and recognise and develop individual talents.

Each module's total grade of 15 European Credits (ECs) is contributed to by all the parts of the module. Some modules are graded as one unit. Others have the units graded separately, for instance each first-year mathematics unit usually has its own test with the grade contributing to the final single grade for the module.

The shift to the Twente Educational Model with its focus on project-based learning undoubtedly came with challenges. An obvious one was the need to design a suitable project for each module. In some cases existing projects could be adapted but in many cases entirely new projects needed to be created. A challenge experienced by the mathematics department was to continue teaching primarily the same content while living up to the potential of TEM by relating to non-mathematics units in the modules. In certain cases this was done by re-ordering the topics strategically (such as in my Calculus 1 course where differential equations are taught unusually early) or by interleaving two similar courses to create one course which can serve the needs of different groups of students.

In 2017, Visscher-Voerman and Muller reported on a suite of quantitative and qualitative evaluations on the success of TEM and concluded that the curriculum restructuring at UT has been successful, although work is still to be done. Visscher-Voerman and Muller's measures of success of TEM included increased student appreciation, increased student success rates and increase in innovative methods of teaching and assessing. Van den Berg et al. (2015) posit that a fully introduced TEM would take at least seven years. Below I present two modules as examples of the Twente Educational Model in practice, some six years after initial implementation, module 1 of Advanced Technology and module 2 of Electrical Engineering. The Advanced Technology module is a good example of a module that is self contained, while the Electrical Engineering module is a good example of a module that is interrelated with other first-year modules.

TWO MODULES AS EXEMPLARS OF THE TWENTE EDUCATIONAL MODEL

Advanced Technology Module 1: Mechanics

The department of Advanced Technology in the faculty of Science and Technology offers a bachelor's programme that aligns well with the Twente Educational Model's two aims of providing interdisciplinary education and producing graduates who are prepared to deal with a rapidly changing technological world. The programme combines knowledge and skills from "electrical engineering, chemical engineering, applied physics, mathematics, and mechanical engineering in a context that is both commercial and society-conscious" (Department of Advanced Technology, UT - Bachelor's Programme in Advanced Technology). The first module in the first year of the programme is called Mechanics and is designed to provide a first encounter with the world of engineering (Department of Advanced Technology, UT - The First Year of Advanced Technology). Over a period of ten weeks, students learn to model dynamic systems through engaging in one of a large number of offered projects. Their work in the project is supported by a unit on calculus, a unit on mechanics and training in laboratory work and experimental procedures.

The projects all involve a story and a problem, a research question, an experiment and a goal. The projects all involve having to develop a model using differential equations. The fifteen topics at time of writing include archery, car suspension, golf, gyroscopic spacecraft control, pole vaulting, rocket propulsion, roller coaster design, seismometers and swings. The students are also provided with some keywords relating to their model. For example, for pole vaulting the keywords are mass and spring systems, oscillations, bending, inertial versus non-inertial reference frame. "Rather than being separate parts, the intent is to have coherence between the various subjects. To this end the project integrates mathematics and mechanics and forms the playground for achieving a deeper understanding of the subjects as well as developing the academic skills" (Department of Advanced Technology, UT – Bachelor's Programme Advanced Technology: Information Guide 2019, p. 10).

The mathematics unit is Calculus 1 and covers differential equations, differentiation, functions and limits, introductory vector analysis, complex numbers, logic, sets and proofs. In order to meet the needs of the Mechanics module, differential equations are covered in the first three weeks of the mathematics course. Solutions to second order differential equations require complex numbers, so that topic is covered in some detail in the second week.

The unit on mechanics covers the topics of Newton's laws of motion in translational and rotational domains, conservation of momentum, angular momentum and energy, rotation and static equilibrium. Free body diagrams are used to analyse static and dynamic motion and mechanical second order systems, such as springs and dampers, are studied.

The laboratory practice unit aims to develop basic skills for carrying out experimental work, such as formulating hypotheses, planning an experiment and laboratory safety. Data acquisition, data processing and error handling are covered as is the importance of keeping a systematic journal. A basic course in Matlab is offered within the laboratory practice unit for programming.

A sequence of one-off workshops is also offered as general support for the module and the project. These include a review of school mathematics, *LaTeX*, use of *Mathematica*, presentation skills and academic writing in English.

In groups of about eight, the students work on their projects throughout the module. The supporting units are presented in different ways depending on their nature; for instance calculus is presented relatively traditionally in the form of lectures and a combination of traditional tutorials and interactive small classes called "guided self study". Mechanics, in contrast, is presented in a sequence of blocks of preparation session, short lecture and tutorial on chosen problems.

The entire module is graded with a single result out of ten (with a passing grade of 5.5) which is a weighted average of the assessment grades of all the supporting units; calculus and mechanics grades are determined through tests, lab practice through journals and hand-in assignments on lab assignments, error analysis and programming skills, and the project itself is graded on group work, the final submitted report and the project presentation and ensuing discussion.

Electrical Engineering Module 2: Electric Circuits

The Department of Electrical Engineering offers a bachelor's degree designed to equip graduates with knowledge and skills applicable to a wide range of technical fields. With the types of research carried out at the university, the students get the opportunity during their degrees to work on cutting edge high-tech applications, such as robot-supported surgery. The bachelor's programme begins with a module introducing the students to electrical engineering and electronics and then continues with the second module called Electric Circuits. The focus of the second module is on learning to systematically analyse electrical circuits of passive elements. The students learn how to model a circuit using ideal circuit elements and ideal element equations in order to analyse both dynamic and static behaviour of the system (Department of Electrical Engineering, UT - The First Year of Electrical Engineering; Spreeuwers, 2018a).

The single project which forms the core of the module requires the students to "design and build a so-called solar inverter, which is used to convert the DC power of a solar panel into AC power and feed it into the power grid with maximum efficiency" (Spreeuwers, 2018a, p. 8). Early in the module the students begin to prepare for the project which is fully realised in an intensive two week period at the end of the module. All materials, such as solar panels, are provided. A small prize is awarded to the group which the most efficient solar inverter (Spreeuwers, 2018a, 2018b).

The mathematics unit completed by the students during module 2 is Calculus 2. This unit deals with sequences and series, integration theory and sundry techniques for solving integrals, as well as an introduction to multivariable calculus. Certain skills are employed immediately in the second module (such as integration) while others are preparation for the vector calculus unit included in the third module.

The circuit analysis unit addresses the behaviour of passive analog circuits and presents methods for analysing circuit models. It emphasises systematic analysis methods such as the node voltage method, convolutions, Fourier series, Bode diagrams and 2-port circuits.

In the unit on laboratory work, the students test the ideas of circuit analysis in practice and deepen their understanding of the concepts. The students are taught to use a journal during the course of the lab assignments for purposes of validity and replicability and thereafter to write a scientific report. Core to the lab work is generating hypotheses based on models of systems and then testing those hypotheses through observation (Spreeuwers, 2018a, 2018c).

From the point of view of mathematics, the first four modules of electrical engineering are more easily understood as a connected unit, rather than four individual modules. The second module is a good example of this across-module network. The second module requires skills encountered in module 1 (solving differential equations and working with complex numbers) and module 2 (integration, partial derivatives, series) and alludes to topics only to be encountered in module 4 (solving systems of linear equations).

Calculus 2 is taught through lectures, interactive small classes (called guided self study) and tutorials. Circuit analysis is similarly taught, however is assessed through multiple small tests rather than the single large test in calculus. Laboratory practice consists of eight weekly assignments which are individually graded.

Commonalities and differences

Other than certain large scale constraints, such as each module being worth 15 ECs, the teaching team and module coordinator of each thematic module have freedom to choose how each disciplinary unit is taught and assessed and how the different parts of the module can be designed to work together for a coherent purpose. The two modules described here are similarly structured but do have some striking differences, such as a wide variety of projects in Advanced Technology module 1 and only one project in Electrical Engineering module 2. The institution-wide nature of TEM imposes a structure across every department and every faculty, which has advantages such as students in modules 9 and 10 being able to choose "minor" modules from anywhere else across the university and have them seamlessly fit into their own degree structure, but simultaneously allows freedom to structure each module in ways which might differ markedly from other modules even in the same department.

An important part of the success of the system relies on the teaching team working together. For the two modules described above, each module's team consists of the module coordinator, lecturers for the relevant units, the laboratory manager, the project manager, the study advisor (for guidance and counseling of first-year students (CELT, 2017)) and possibly senior tutors. Effective teamwork among the teaching staff is essential to the modules' success (see also Cornejo et al., 2018). Of particular note is the evaluation process each module undergoes; at the end of each module, students have the opportunity to evaluate the course both in a Likert-style questionnaire as well as in long form responses. These comments are collated in an evaluative report and lecturers are required to respond to any complaints or suggestions for change. These responses are recorded, are expected to be acted upon, and are included for review in the following year's similar evaluative report.

DISCUSSION

Problem-based learning at the University of Twente takes different forms from module to module and from department to department. Certain modules are fully integrated single "atomic" units which cannot be usefully broken down into parts while others, such as the ones discussed in this article, have units that cohere with one another but are still recognisable as parts unto themselves. Other institutions structuring curricula in a similar way to the UT (Cornejo et al., 2018; Edström and Kolmos, 2014) also allow a variety of different modes of cohesion across the institution. Certainly at the first-year level the TEM projects are what Edström and Kolmos would term "discipline projects", ones where the students apply theoretical knowledge to relatively strongly framed practical problems, such as modeling the flight of an arrow in advanced technology or designing a solar inverter in electrical engineering. In the second and third years of the bachelor's programme the projects become "problem projects" where the problems to be addressed become increasingly ill-structured and complex. In this context of increasing participation in the engineering discursive community, TEM could be seen as encouraging the development of a discursive or core identity as an engineer through active engagement with engineering practice and discourse (Allie, Armien, Burgoyne, Case, Collier-Reed, Craig, Deacon, Fraser, Geyer, Jacobs and Jawitz, 2009; Craig, 2011; Craig, 2013).

Throughout the TEM modules, transferable non-technical skills are foregrounded as important. In each module the students need to write a report and present their work in front of an audience. In certain cases, such as in module 1 of Advanced Technology, writing skills and presentation skills are explicitly covered in dedicated workshops. Throughout the entire bachelor's programme the students have to work in groups where the workload necessarily needs to be shared between the group members. Research has shown that teamwork develops graduate skills that are valued by employers (King et al., 2017) and that active learning pedagogies, of which PBL is one, are aligned with teaching for equity (Tang, El Turkey, Cilli-Turner, Savic, Karakok and Plaxco, 2017), although concern has been raised (Beddoes and Panther, 2018) that teamwork practices could exacerbate gender inequalities in engineering. An investigation of gender inclusive teamwork practices in TEM could be an avenue for further research.

In addition to a group grade for the project report each member of the group is assessed individually on the same content, for instance through a short interview or a poster presentation. If one member of a group has failed a module and the rest of the group has passed, it will not be on the basis of the group work component but on another unit (such as calculus), which can then be reassessed through a second written test or an oral exam. A challenge is how to assess group project reports when some groups may have taken on additional strain due to members dropping out. In such cases the assessment has to take such difficulties into account and, again, interviews can help the teachers determine what is fair.

In some ways, mathematics is the unit that fits least well into the modules. Certainly, the topics covered in the mathematics courses are needed in the modules, but there is tension between internal coherence within the sequence of interrelated mathematics courses (Calculus 1, Calculus 2, Vector Calculus) and coherence within the modules of which the mathematics courses are disciplinary units. The two modules discussed here are examples of that dilemma. In Advanced Technology module 1 (and indeed Electrical Engineering module 1, not discussed here) differential equations are covered first because of the demands of the Advanced Technology and Electrical Engineering units, however the rest of Calculus 1 is a selection of topics required to lay good groundwork for the two courses of calculus that follow and are not necessarily included for the Advanced Technology and Electrical Engineering modules themselves, such as limits, continuity and finding extrema. In Electrical Engineering module 2, the module requires very little of the calculus covered in Calculus 2 (mostly only needing integration techniques), primarily using differential equations skills taught in Calculus 1. Pedagogically speaking, it is not sufficient that the students encounter mathematics topics that their teachers know they will need, but that they can see the relevance of that mathematics (Dunn, Loch and Scott, 2018). Each first-year mathematics course is taught with one traditional two hour lecture per week, followed by small interactive classes called “guided self study” within which the teacher has the opportunity to choose exercises that are contextualized with the students’ study programme in mind if she chooses, and relatively traditional tutorials. Each programme has the opportunity to request that a “case study” also be included. The two modules discussed in this paper do not have case studies, but an example would be module 3 of Civil Engineering where a case study on traffic flow is included to make explicit connections between the (otherwise rather general and abstract) linear algebra unit included in that module and the civil engineering context. Ensuring that the sequence of first-year mathematics courses maintains an internal coherence while still cohering with the needs of the modules requires constant communication amongst the module team of teaching staff and is a matter of ongoing development.

Assessment remains a troublesome part of TEM. At time of writing, each module is passed or failed as a unit, which is worth 15 European Credits (ECs). The various parts of the module such as the project and its supporting disciplinary units all contribute to that module grade, often through a weighted average involving certain conditions or subminima. In modules such as the ones discussed here it is possible to pass all but one unit (for example the mathematics unit) and therefore have to repeat the entire module. This baseline requirement of TEM is not accepted in all departments; some modules structure their assessment requirements such that only parts of a module need be repeated. At the institution, the possibility of formally breaking up the “all or nothing” structure to make it possible to repeat only one part of a module is under discussion and is likely to be carried out. Another assessment challenge is how to introduce more formative and less summative assessment and thereby perhaps make assessment more student-centred (Visscher-Voerman and Muller, 2017; van den Berg et al., 2015). Graham (2012) observes that even very successful and institution-wide engineering education reform is vulnerable to a “drift” back to a traditional curriculum. On the other hand, Graham also observes that curriculum reform proves resilient if there is “an on-going focus on educational innovation and reinvention” (Graham, 2012, p. 3). Time will tell if the breaking up of the module grade is a sign of TEM drift or of reinvention.

CONCLUSIONS

The Twente Educational Model (TEM) has two primary foci. The first is the incorporation of interdisciplinarity into the curriculum to reflect the interdisciplinarity present in the institution’s research and that present in the industries and fields into which UT graduates may go. The second focus is to prepare its graduates for a rapidly changing world by teaching them current and valuable technical skills as well as transferable non-technical skills related to communication, presentation and effective teamwork. Six years of implementation of the model have resulted in a mature system of project-based modules which are continually being evaluated for strengths and weaknesses.

Edström and Kolmos (2014) suggest three learning principles to guide the practice of project-based learning; I argue that TEM adheres to all three. First, the cognitive learning components of the modules are addressed through contextualised problems at the heart of the projects. The students need to analyse and define the problems which in the first year are generally well-defined. Secondly, the curriculum content in any module is interdisciplinary with skills from different disciplinary units needed to support the projects, such as calculus and circuit analysis. Thirdly, the social approach which is crucial to effective PBL is fulfilled by working in teams where communication occurs within and between teams; knowledge is created collaboratively.

After an in-depth study of engineering education reform across multiple institutions, Graham (2012) concludes that successful systemic change is often driven by “significant threats to the market position of the department/school” (p. 2). Certainly market forces did play a role in the university’s decision to bring about institution-wide change (Visscher-Voerman and Muller, 2017; van den Berg et al., 2015), but it is not enough for those market or other external forces to be present; throughout the institution the need for radical and curriculum-wide reform needs to be acknowledged and acted on with support from university leaders and management. Allowing plans for change to be influenced by current educational theory and innovative practice (in this case PBL) can result in successful and enduring reform.

This paper aims to contribute to the literature on curriculum renewal in higher education by presenting the Twente Educational Model and two successful implementations of the model in advanced technology and electrical engineering. While challenges still exist and details continue to change, the Twente Educational Model is an example of mature curriculum reform at a technical university that offers students an interdisciplinary education which can prepare them for a rapidly changing world.

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