Supporting Flexible Learning Pathways Through the Development of a Digital Flexible Math Tool with Adaptive Items and Elaborated Feedback

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Table of Contents

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Abstract

Higher education institutions have the mission of promoting social, cultural, and economic development. The adoption of flexible learning pathways strategies has been essential to facilitate students access and create an inclusive learning environment. Nevertheless, the provision of flexibility challenges teachers to offer a differentiated instruction that fulfils the needs of a diverse student body. Therefore, this study investigates how the development of a Digital Flexible Math Tool (DFMT) with adaptive items and elaborated feedback supports the flexible model provided by the Build-up Course Mathematics, part of the Creative and Technology bachelor programme at the University of Twente. To achieve this, four-phase educational design research was conducted. The first phase was aimed at getting insights into the context of the course. From this, by examining the design ideas aligned with the context, a prototype of the DFMT was built. The third phase examined the perceptions of teachers and students towards the developed solution. Finally, the fourth phase reflected upon the designed solution and its possible use in the course. In general, the participants of this study reported positive perceptions towards the DFMT. Additionally, recommendations to guarantee the effective integration of the digital solution into the Build-up Course Mathematics in the future were made. Further research is advised to investigate the impact of the DFMT on students registered to the Build-up Course Mathematics.

1. Introduction

The mission of worldwide Higher Educational Institutions (HEIs) is to promote social equity and economic growth through the provision of quality and effective education which meet the demands of the labour market supporting learner's lifelong learning skills. Therefore, HEIs have been adopting Flexible Learning Pathways (FLP) strategies that ensure wider access to the educational system and provide choices about students individual' learning path. Although the strategies of FLP have not been clearly defined, they aim to "provide multiple entry points to and progression routes between institutions, courses, or educational levels which benefit individuals and society in terms of equity, employability, or efficiency" (UNESCO, 2018)

One of the dimensions of FLP refers to flexibility in admission which implies the elimination of entry requirements, recognition of prior knowledge, diversification of the programmes, and credit transfer arrangements among institutions, courses, or educational levels aiming to make the higher education system more attractive (Moitus, Weimer, & Välimaa, 2020; Ling et al., 2001). In the Netherlands, flexible entry levels are seen by regulations that allow students with a Dutch HBO or VWO diploma to transfer to bachelor programmes at the university level (Rijken, Maas, & Ganzeboom, 2007). Moreover, The Bologna Declaration of 1999 enhances students' mobility among 45 European HEIs. Also, The Erasmus Mundus Joint master's degree aims to attract not only European students but also students from around the globe (European Union, n.d.).

The increasing number of students entering HEIs might be a consequence of the flexibility in admissions aforementioned. Martin and Godonoga (2020) have reported a significant rise in global tertiary education gross enrolment since 1974. In the context of Dutch education, the number of students registered at HEIs has tripled during the last two decades (VSNU, 2021). The proliferation of the higher education system has attracted students from various backgrounds, socio-economic status, and learning skills and abilities (Martin & Godonoga, 2020). For example, in 2020, 76.6% of the students enrolled in Dutch universities are from European countries while 23.3% are international (i.e., non-European) (VSNU, 2021). This challenges HEIs, especially teachers, which frequently find highly heterogeneous groups of students in the same classroom, to provide lessons that meet all the students' needs.

In the context of math education, teachers are struggling with the diversity of abilities of students at the entry-level. Besides, OECD (2021) has reported a decrease in the mathematical performance in the PISA-based test for schools since 2003. The lack of mathematical literacy means that students are unable to ‘reason and solve problems and interpret situations in personal, occupational, societal and scientific contexts’ (OECD, 2021). Thus, students at tertiary entry-levels are lacking basic math skills which implies an added difficulty in understanding higher-level math courses (Jourdan, Cretchley, & Passmore, 2007; Lawson, 2003). Additionally, the low performance caused by the lack of appropriate skills influences the dropout rates phenomena in HEIs (P. Edwards & P. M. Edwards, 2003), which at the same time create a workforce deficit in the demanding STEM industry (van den Hurk, Meelissen, & van Langen, 2019). Therefore, HEIs urgently require the adoption of strategies that tailor students’ needs and offer personalised learning choices.

The Build-up Course Mathematics offered to first-year students of the Creative Technology Bachelor’s programme (CreaTe) at the University of Twente, is a course created in response to the lack of mathematical literacy in entry-level students. It aims to prepare students for advanced math courses included in the programme curriculum. Nevertheless, teachers and the teaching assistants continue struggling with the heterogeneity in student's math abilities.

This study intends to develop a Digital Flexible Math Tool (DFMT) for the Build-up Course Mathematics that offers personalised learning through the integration of adaptive items and elaborated feedback, which would allow students to progress at their own pace despite their academic level. To achieve the goal, the current study is developed in an educational design research constituted by four phases. The first phase intends to obtain a clear description of the course, teacher, teaching assistants and students. In the second phase, the prototype of the DFMT would be designed and developed. The evaluation of the prototype would take place in the third phase. The last phase aims to reflect on the design solution and the possible use of the DFMT.

The following report is depicted in six chapters. The first chapter contains the introduction of the study. The second chapter presents the theoretical framework followed by the research (sub) questions. Chapter four describes the methodology used in the study. Chapter five and six the results and the discussion of each phase are presented respectively.

2. Theoretical Framework

Flexible Learning Pathways

The adoption of the Flexible Learning Pathways (FLP) aims to raise equity, inclusiveness, and efficiency among higher educational institutions (Martin & Gonodoga, 2020). FLP facilitates students’ access to tertiary education providing transferability within different level institutions and recognizing student’s prior knowledge, but also give students the option to choose their most convenient learning pathway once their access is guaranteed (Moitus et al., 2020; Ling et al., 2001; Collis, Vingerhoets, & Moonen, 1997). The effective, but complex provision of FLP is influenced by policies, instruments and practices that require the action of governments, institutions, and individuals (Martin & Gonodoga, 2020; Moitus et al., 2020). For that reason, this study depicts FLP in two levels: flexibility in admission and flexibility during studies.

Flexibility in Admissions

The IIEP-UNESCO (2019) states that flexible learning pathways are supported by the provision of "(re) entry points at all ages and all educational levels, strengthened links between formal and non-formal structures and recognition of knowledge and skills". As a result, HEIs have been adopting policies that improve access conditions such as removing entry requirements, easing mobility among institutions (i.e., transferability), courses and educational levels, and diversifying the programmes (Martin & Gonodoga, 2020; Ling et al., 2001).

Particularly, the Netherlands has increased its transferability since 1970 when the Dutch Ministry of Education allowed students with different levels of degrees (e.g., HBO and VWO) to be admissible to bachelor programmes at the university level (Rijken, Maas, & Ganzeboom, 2007). As a result, the number of students holding an HBO diploma transferring to university bachelor's degree programmes has increased by 10.4% in 2019 (VSNU, 2021). Moreover, The Bologna Declaration of 1999 enhances students' mobility among HEI of 45 European countries making the European-higher-education system more attractive and competitive as well as inclusive and accessible. This was possible through the introduction of a credit transfer system (ECTS), recognition of international diplomas and implementation of three-cycle educational systems constituted by bachelor's, master's, and doctoral studies. As a consequence, the

Association of Universities in the Netherlands (VSNU) reported in 2021 that the number of students registered in bachelor, master and doctoral programmes at Dutch universities coming from the European Economic Area is almost double the number of students registered in 2015.

Internationalization in HEIs could be a strategy that promotes accessibility as well. For instance, The Erasmus Mundus Joint master's degree is an EU-funded programme aiming to attract students around the world (especially from developing countries) to study in European Universities (European Union, n.d.). Analogously, van der Wende (2001) indicated the introduction of accreditation and the use of English as a language of instruction are measures adopted by various European countries to increase the number of international students. As a result, the number of international students, non-European, enrolled in Dutch universities in 2020 has increased more than double compared with the number of international students enrolled in 2015 (VSNU, 2021).

Flexibility During Studies

The flexibility in admissions has increased the number of students entering HEIs which led to a higher diversity of the student body. For example, working, part-time, international and returning students (including adult students) are a significant portion of the student group of tertiary education (Martin & Gonodoga, 2020). Therefore, effective FLP must allow students to choose when, where, how and what to learn to fulfil their academic needs (Martin & Gonodoga, 2020; Gordon, 2014; Ling et al., 2001; Collis et al., 1997).

Providing students choices regarding their individual learning path means raising the diversity of learning materials, information banks, communication channels and tools (Collis et al., 1997). Such diversity was categorised by Gordon (2014) as *pace* – when and what is learned, *place* – where is learned, and *mode* – how is it learned. This has been facilitated by the development and use of technology (Moitus et al., 2020; Gordon, 2014; Higgins & Northover, 2011; Lane, 2011).

The benefits of technology in education have been a subject of study. Its use allows the integration of computer-based learning, computer-based assessment and open learning which benefit HEIs in terms of cost and efficiency (Poon, 2013; Ling et al., 2001). Particularly, the integration of technology in the classroom allows teachers to track students' progress, efficacy in lesson preparation and delivery and reduction in the workload (Higgins, Huscroft-D'Angelo, & Crawford, 2019; Poon, 2013; Yen & Lee, 2011). Regarding the students' benefits, e-learning has shown a positive influence on students' self-efficacy, motivation, participation, and academic achievement (Moreno-Guerrero, Aznar-Diaz, Cáceres-Reche, & Alonso-García, 2020; Setyaningrum, 2018; Smyth et al., 2012; Gecer & Dag, 2012).

In the context of FLP, the technology guarantees several ways to give access to content information, allowing teachers to tailor students' needs adapting the content in diverse modalities such as audio, visual or textual (Gordon, 2014). The study of Gordon (2014) pointed out several FLP's models enabled by technology: (1) flexi-level which is an assessment model that aims to deliver adaptive questions; (2) Knowledge Network which delivers adaptive content based on students' achievement; and (3) Flexible Module model based on choices not only about the content but also assessment. Particularly, flexi-level assessment approach provides more accurate measurement at almost all ability levels (Betz & Weiss, 1975). Additionally, its administration through computer-based environment reduced the level of complexity of the instructions given to the students (Weiss & Betz, 1973). Moreover, the study of Sampson and Karagiannidis (2002), reported that the use of technology is essential to automatically adapt content to the characteristics of individual learners.

Another initiative that uses technology as a facilitator of FLP is the well-known Open Educational Resources (OERs). OERs were first developed and implemented in 2001 in response to the need for inclusive and accessible learning environments that support social equity and economic growth (D'Antoni, 2009). OERs were recognized and defined by UNESCO in 2002 as "teaching, learning, and research (digital) materials, that reside in the public domain under an open license that permits no-cost access, use, adaptation, and redistribution". In other words, OERs are accessible at anytime, anywhere, and are free of cost. Also, its modifiability ensures up-to-date content and the opportunity to adjust knowledge based on the target audience (Miao, Mishra, & McGreal, 2016). Therefore, OERs are aligned with the flexible learning principles making education affordable, reusable, and inclusive.

Nowadays, there are over 2,500 open access courses from over 200 universities (Joyce, 2006) which implies that its use has been massively spread. Nonetheless, there are some barriers that HEI must overcome to ensure the effectiveness of OER. The study of Murphy (2013) indicated that even though teachers and students are highly aware of the existence of OER, this is not reflected in its adoption. Thus, Murphy (2013) suggested policy frameworks, teachers' guidance and support to enhance OER' usage. Regarding OERs' modifiability, teachers and students are highly concern about the quality of the material included in the open sources as well as the copyright issues (D'Antoni, 2009). Other barriers experienced not only in the adoption of OERs but also in the use of technology in learning environments are related to connectivity and technical support (Miller & ONiell, 2014; Ling et al., 2001); students' heavy cognitive overload (Chu, 2014); and detriment to students' attendance (Bell, Cockburn, McKenzie, & Vargo, 2001).

The provision of FLP is a complex process because it requires collaborative work and effort of the government, tertiary institutions, and teachers-learning process. From the governmental view, policymakers need to facilitate access and transferability to HEIs (Martin & Godonoga, 2020; Ling et al., 2001) which at the same time requires governmental funding that enhances the implementation and development of technological learning platforms (Moitus et al., 2020). This could be seen as a drawback because the study of Chen (2003) alleged that the costs of courses with flexible delivery are doubled compared with traditional courses. At the institutional level, cooperation between secondary and higher-level institutions is essential to guarantee students' smooth transition to tertiary education (Moitus et al., 2020). Also, the effective provision of FLP demands teachers' training to improve their digital literacy and reliable technological infrastructure (Winter, 2002). Finally, from a teacher-learning perspective, teachers need to invest more time in content creation (Chen, 2003; Collis et al., 1997) and students need to be guided in their choosing process to ensure the effectiveness of FLP (Ling et al., 2001).

Personalised Learning in the Form of Adaptive Items

Despite the massive use of technology in learning environments, most educational sources found on the internet have standardised content without considering the heterogeneity of the student body, their needs and skill/knowledge. Personalised Learning (PL) is an educational model which aims to provide customised education tailoring study programmes to students needs and interest considering their skills, knowledge, attributes, and backgrounds (UNESCO, 2012). Although there is not a consensus definition of personalised learning, the U.S. Department of Education (2010) stated that PL is a model "which focuses on what and how is taught to match what people need to know, how they learn, where and when they will learn, and who needs to learn”.

Often, PL is related to e-learning environments because technology enables automatic, dynamic, and adaptable content through programmed algorithms (Kerr, 2016)). Also, the U.S. Department of Education (2010) indicated that the adoption of technology in learning environments empower students to take ownership of their learning process due to the provision of flexible provisions (e.g., pace, mode, and place) and self-awareness of their weaknesses and achievements. Therefore, the use of technology is indispensable to provide PL.

To deliver PL it is essential to recognise and understand students’ strengths, weaknesses and interests (UNESCO, 2012). This can be done through assessments or adaptive content/items. This means that ‘the learner’s interaction with the previous content determines the nature of materials delivered subsequently’ (Kerr, 2016). This idea was first introduced by B.F Skinner in 1958 with the development of an automatic testing device that operates differently based on the user's performance (Karamouzis, 2006). That is if the student chooses the right answer, the device moves to the next item, however, if the answer is wrong, the student will have several trials until he/she chooses the right answer (Karamouzis, 2006). Similarly, Gordon (2014) reported other methodologies that support FLP and enhance personalised learning.

Nowadays, some initiatives have been developed aiming to tailor students’ needs, considering their individual skills levels and backgrounds. For instance, The Knowledge-on-Demand project is an initiative where different learners receive different learning materials adapted to their profile through the design, development, and validation of open platforms (Sampson & Karagiannidis, 2002). Karagiannidis and Sampson (n.d.) assured that the use of intelligent and adaptive educational applications (such as the KOD) increases instructional effectiveness and efficiency which means better performance in less time. Additionally, the study of Yarandi, Jahankhani, and Tawil (2012) reported a positive impact on students' satisfaction with the use of an adaptive e-learning decision support system in the context of mathematics education.

Despite the positive impact of PL achieved through the use of adaptive content/items, its development is very complex. As described in the policy brief of UNESCO in 2012, the identification of students' strengths, weaknesses, and learning needs is fundamental to provide effective PL. Nonetheless, such identification might imply some issues. For instance, the study of Huang and Shiu (2012) pointed out that the experts who choose the learning material tend to overestimate learners' knowledge level. In the case of the adaptive system described by Yarandi et al. (2012), an enormous data collection is needed to provided content tailored to students' abilities, which might lead to privacy concerns. Last, the lack of social interaction in personalised e-learning platforms might cause students' isolation (UNESCO, 2012).

Another challenge experienced by the provision of PL is the use of personalised feedback. The study of Saul, Runardotter, and Wuttke (2010) indicated that despite the development of several adaptive hypermedia systems aiming to provide assessments that targets students' needs, few evidence has been found regarding personalised feedback in e-learning systems.

Feedback

Feedback is the information provided to students regarding their performance and understanding of a specific task (Saul et al., 2010; Hattie & Timperley, 2007; Black & Wiliam, 1998). Feedback can be delivered in multiple ways, for instance, it can involve corrective information, clarify ideas, provide encouragement or strategies to eliminate the gap between current and desired understandings (Hattie & Timperley, 2007). The study of Hattie and Timperley (2007) classified different forms of feedback into four types: feedback about the task (FT), which indicate how well the task has been performed; feedback about the processing of the task (FP) which give cues or strategies for error detection; feedback about self-regulation (FR), related to students' monitoring their progress or action-regulation toward the learning goal; and feedback about the self as a person (FS) which usually refers to positive reinforcement to impact student attitudes towards a task.

Technology has played an important role in feedback delivery. The integration of computer-based learning environments has allowed learners to receive feedback right after the task has been performed. This is called immediate feedback which is defined by Dempsey and Wager (1988) as "informative, corrective feedback given to a learner as quickly as the computer's hardware and software allow during computer-based instruction or testing". The study of Skinner (1958) mentions how the teaching machine developed by Sydney L. Pressey allows students to take an active role in their learning process due to the provision of immediate feedback. The time machine described by Skinner (1958) consisted of allowing the users to move to the next question if their answer was correct, but if the answer was incorrect, users have several trials until they input the right answer. Although immediate feedback described by Skinner refers to the correctness of the answer, feedback provided by modern computer-based learning environments includes feedback about the task, self-regulation or rewarding. Duolingo, for instance, is a language learning application that allows users to track their progress, verify the correctness of their answers and be rewarded for it. All this information is provided to the user instantaneously.

In the context of math education, the effect of feedback in math e-learning environments has positively impacted students learning process. For example, the study of Morton and Qu (2015) reported that e-tutors play a significant role in the student's understanding of mistakes and improvement of problem-solving skills. Also, Krause, Stark, and Mandl, (2009) found that feedback provision supports statistics knowledge acquisition in an e-learning environment. Although e-learning tools facilitate the extensive provision of feedback, Hattie and Timperley (2007) assured that not all the feedback supports students learning. In fact, delivering cues, reinforcement, video or audio feedback, and computer-assisted instructional feedback are the most effective forms of feedback (Hattie & Timperley, 2007).

Another type of feedback that has been beneficial in the context of math education is elaborated feedback (EF). Dempsey, Driscoll, and Swindell (1993) defined EF as the explanation for why the learner's response is correct or incorrect and allows the learner to improve the response. In math education, EF is given by detailed cues or an explanation in the form of step-by-step problem-solving (Wang, Gong, Xu, & Hu, 2019). The study of Fyfe (2016) showed that elaborated feedback in algebra assessments supports students learning. Additionally, Wang et al. (2019) affirmed that the provision of EF has a positive impact on students' performance but also on motivation. Nevertheless, the length or complexity of feedback must be considered. Shute (2007) discussed that long or complex feedback may distract learners or deliver a diffuse message discouraging students to progress. Currently, the amount of information provided to ensure effective feedback is unclear (Shute, 2007).

The increase of technology use in learning environments has allowed to use of videos aiming to reduce the gap between the current knowledge and the desired learning. Video-feedback simulates a virtual tutor that guides students to obtain correct answers. Budgetary reasons and the raise of students enrolled in HEI's are some of the reasons that enhance the use of video-feedback (Donkin, Askew, & Stevenson, 2019). In fact, several studies have found video-feedback as an effective way to increase students' learning outcomes (Donkin et at., 2019; Ostrow and Heffernan, 2014). The effectiveness of videos in feedback delivery is supported by the multimedia principles depicted by Mayer (2014) where the combination of words and images increase the human capacity to processing information. Additionally, Clark and Mayer (2003) found that the use of videos in e-learning platforms promote learning since the use of visual and auditory information enters is stored in the permanent or long-term memory. This view is supported by Ostrow and Heffernan (2014) who reported positive outcomes after the use of video feedback by 8th-grade students in a Geometry course, and Morton and Qu (2015) who stated that video positively influences students problem-solving skills.

3. Research Questions

The main goal of this study is to investigate: ***How the development of a Digital Flexible Math Tool with adaptive items and elaborated feedback supports the flexible learning pathways model adopted by the Build-up Course Mathematics offered by the CreaTe Programme at the University of Twente?*** To answer it, four-phase educational design research was conducted. First, the context of the Build-up Course Mathematics was analysed. Second, the prototype of the Digital Flexible Math Tool was designed and developed. Third, the evaluation and refinement of the prototype took place. Finally, reflection and recommendations are made. Therefore, research sub-questions are formulated in each phase of the study:

Sub-question phase 1

What are the characteristics of Build-up Course Mathematics provided to first-year students of the CreaTe programme at the University of Twente of the University of Twente?

Sub-question phase 2

How to develop a digital tool that addresses the needs of the students and teachers of the Build-up Course Mathematics?

Sub-question phase 3

What are the perceptions of the students and teachers of the Digital Flexible Math Tool developed for the Build-up Course Mathematics?

Sub-question phase 4

Which characteristics of the Digital Flexible Math Tool can be improved to facilitate its possible integration into the Build-up Course Mathematics?

4. Methodology

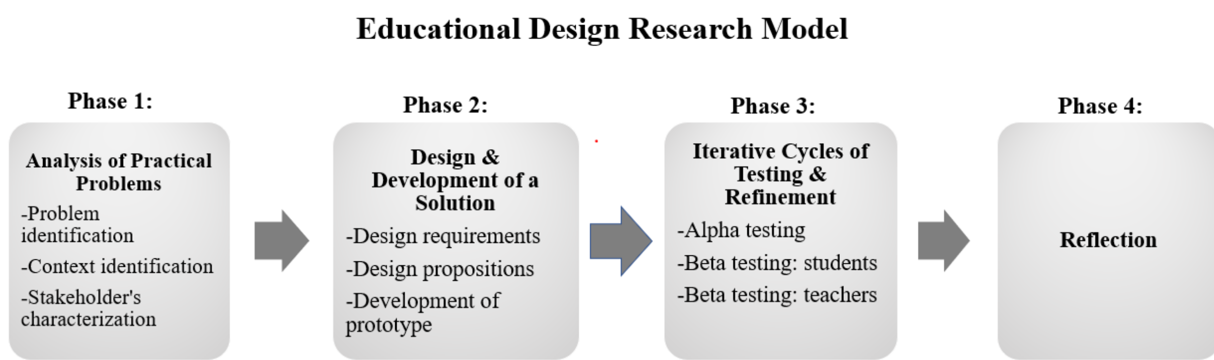
4. 1 Design

The purpose of this study was to find a practical technological solution for the challenges faced by teachers and students in the Build-up Course Mathematics offered to first-year students from the Creative and Technology bachelor’s programme at the University of Twente (UT). Educational design research with a technological perspective was conducted as suggested by

Reeves (2006). The research distinguished four phases: Analysis of Practical Problems, Design and Development of a Solution, Evaluation: Iterative Cycles of Testing & Refinement, and Reflection (see Figure 1).

Figure 1

Four-Phase Educational Design Research Used in this Study



As suggested by McKenney and Reeves (2019), analysis of practical problems aimed to provide a characterisation of the course and stakeholders to gain better understandings of the problem and determine the feasibility of change. Design and Development of a Solution aimed to explore possible solutions and feasibility of change in the named context as well as the development of the prototype. Iterative cycles of testing & refinement examined the accuracy of the design solution integrated into the digital tool and teacher's and student's perceptions of the functionality and quality of the digital tool. Also, refinement was done throughout the phase. The last phase of the study attempted to reflect upon the findings.

4. 2 Participants

A group of teachers, the CreaTe programme director, e-learning specialists and students from the University of Twente participated in this study. The selection was non-random purposive sampling because this study aimed to provide a practical solution to a target group in the aforementioned context. The participants were divided into an experts' group and a students' group. Due to the nature of the research, the participants variated according to the phase of the study (see Table 1).

Table 1

Overview of the Methodology Used in this Study

Phase	Name	Research Question	Participants	Instruments	Analysis
1	Analysis of Practical Problems	What are the characteristics of the course Build-up Course Mathematics provided to first-year students of the CreaTe bachelor programme of the University of Twente?	Programme director, teacher coordinator & teacher coordinator assistants	Semi-Structured Interview & Document Analysis	Qualitative & Quantitative
2	Design and Development of a Solution	How to develop a digital tool that addresses the needs of the students and teachers of the Build-up Course Mathematics?	Teacher coordinator & e-learning specialists	Interviews, Meetings, Field Notes, Literature Review, Document Analysis & Virtual Platforms	Qualitative
3	Evaluation: Iterative cycles of Testing, and Refinement	What are the perceptions of students and teachers of the Digital Flexible Math Tool developed for the Build-up Course Mathematics?	Teacher coordinator, teacher coordinator assistants, e-learning specialists & students	Prototype, Grasple Logs, Questionnaires and Meetings	Qualitative & Quantitative
4	Reflection	What characteristics of the Digital Flexible Math Tool can be improved to facilitate its possible integration into the Build-up Course Mathematics?	N. A	Data collected from previous phases & Literature Review	Qualitative

Experts' Group

Respondents of this subgroup were selected through the purposive reputational case sampling which means they were advised by other researchers due to their characteristics. The decision of this method of selection is supported by Cohen, Manion & Morrison (2011) which indicates that purposive-reputational-case sampling is used when participants are recommended by others based on their characteristics. The experts' group was divided into two subgroups: the e-learning specialists and teacher members of the CreaTe programme.

E-learning specialist. Three e-learning (Grasple experts) participated in the study. They varied in age, gender, and years of experience. 67% of responders were male. The age ranged from 25 to 45 years (M = 33, SD = 8.64). The years of experience ranged from 0 to 5 years (M = 2.3, SD = 2.05).

Teachers. The director of CreaTe programme, the teacher coordinator of the course and two teacher assistants of the course were part of this subgroup. The participants in this subgroup varied in age, gender, years of experience, and level of education. 75% of responders were female. The age ranged from 21 to 63 years (M = 40.5, SD = 17.17). The years of experience ranged from 0 to 41 years (M = 17.5, SD = 16.16).

Students Group

Initially, the current study intended to have participants from the CreaTe bachelor programme. Due to the lack of voluntary participation of students of the mentioned programme, the students participating in this study were from various programmes of the University of Twente. Respondents of this subgroup were selected through voluntary sampling which means they must have an active e-mail account from the UT (Cohen et al., 2011).

As well as the experts' group the respondents within this group varied in ages, gender, and nationality (Dutch HBO, VWO and international students). The sample includes 9 students (57% female, 44% male). Students' age ranged from 22 to 33 years (M = 27.21 years, SD = 3.46). 44%

reported being Dutch (22% have an HBO degree), 11% were European (non-Dutch) and 44% reported being non-European.

4. 3 Instrumentation and Procedure

The current research was conducted in four phases: Analysis of Practical Problems, Design and Development of a Solution, Evaluation: Iterative Cycles of Testing, and Reflection. Various instruments were used among the phases of the study to collect qualitative and quantitative data as shown in Table 1. This study was conducted with the Behavioural-Management-and-Social-Sciences Ethics Committee's approval number 2012037.

4.3.1 Phase 1: Analysis of Practical Problems

This phase aimed to gain insight into the problem, context, and stakeholders of the Build-up Course Mathematics. To achieve the goal, three online semi-structured interviews were administered. First, a 30-minutes semi-structured interview was conducted with the programme director of the CreaTe attempting to gain a better understanding of the programme (i.e., curriculum, methodology and organisational structures) as well as the description of the teacher coordinator teacher assistants and students. Second, a 60-minutes interview was administered to the teacher coordinator. It focused on the comprehension of the course design, the role of the course within the programme and students' performance in the course. Questions regarding the course structure, curriculum, methodology, and resources were asked as well as questions regarding the students' performance. Third, a 30-minutes online group interview was conducted with two teacher assistants. The items focused on the methodology of the course and the interactions between the teacher coordinator, teacher assistants, and students. Overall, the items asked in semi-structured interviews were categorised into problem identification, context identification and characteristics of the stakeholders. The scheme of the interviews is attached in Appendix A. All the respondents were reached by email. The decision to administer semi-structured interviews was based on the book of Cohen et al. (2011) which indicated that open-ended items allow the interviewer to ask for clarification or profound given information.

Subsequently, the analysis of the documents which contains student's data was done. Such documents were provided by a pre-U data analyst of the University of Twente and the teacher coordinator of the course. The purpose of this analysis was to characterise the first-year students of the CreaTe bachelor programme and their performance. Moreover, the university website for educational systems is analysed (https://www.utwente.nl/en/educational-systems/). This document analysis is an unobtrusive systematic procedure used to gain understanding and elicit empirical knowledge (Bowen, 2009).

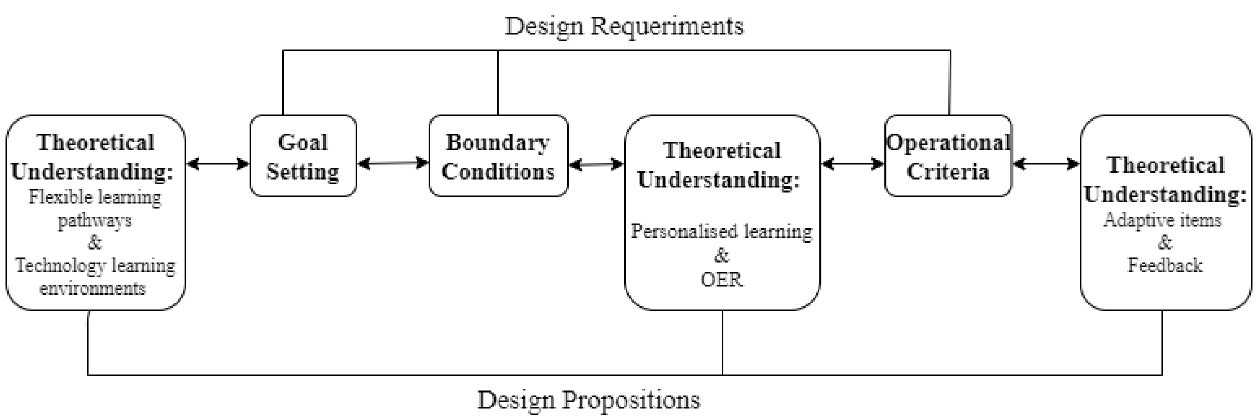
4.3.2 Phase 2: Design and Development of a Solution

The main goal of this phase was to explore the design solution and construct a prototype that reflects some components of the desired DFMT intended to use in the Build-up Course Mathematics in the future. To achieve the goal, the design propositions and design requirements were analysed to gain a complete understanding of what is to be accomplished and how it can be done (McKenney & Reeves, 2019). First, a theoretical understanding of the context is made. Second, based on the analyses derived from the first phase, the goal of the practical solution is determined. Third, using the responses from the interviews conducted in the previous phase, the boundary conditions (e.g., freedoms, opportunities, and constraints) are investigated. Fourth, a literature review is made to gain theoretical understandings related to personalised learning and OERs. Fifth, the operational criteria of Grasple (e.g., technical specifications of the platform) is evaluated using a document analysis of Grasple's tutorials obtained from https://www.grasple.com/. Also, informal meetings with the e-learning specialist served to gain better insight of the functionality of Grasple. Lastly, a new literature review is conducted to obtain a theoretical understanding of what is known about solutions in a similar context. Figure 2 shows a graphical representation of the steps taken in this phase.

After evaluating the design requirements and propositions, the construction of a prototype took place. The prototype was developed in Grasple. As a part of the design, Vimeo, a video platform was used to complement the design solution.

Figure 2

Flowchart of the Procedure in Phase 2



4.3.3 Phase 3: Evaluation: Iterative Cycles of Testing, and Refinement

The purpose of this phase is to evaluate several elements of the prototype constructed such as design solution, the functionality of the tool in practice and students' and teachers' perceptions of the DFMT. As suggested by McKenney and Reeves (2019) two types of testing were conducted (e. g., alpha and beta testing) in three different sessions.

Alpha Testing. Aimed to assess the design solution and its coherence with the theoretical framework and the context as well as the functionality of the first draft version of the prototype built (McKenney & Reeves, 2019). The testing was conducted with three e-learning specialists of the University of Twente in a 60-minutes online meeting. The meeting was used to explain the solution developed. The meeting was recorded for further analysis and the prototype's refinement. After alpha testing and its analysis was made, the first refinement of the prototype took place.

Beta testing. Intended to examine the functionality and the perceptions of the teacher coordinator and students of the refined version of the prototype. In the current research, beta testing was conducted in two separate sessions: students' and teacher' testing.

Beta Testing: Students. This testing served to evaluate the perception of students of the DFMT and the functionality of the refined version of the prototype (second version). First, participants were contacted by email to agree on a date to perform the prototype' testing. Then, individual 60-minutes online meetings were set. Fifteen minutes before each meeting, participants received an email that included the informed consent form, instructions, the link to access the digital tool and the online questionnaire. Once the meeting started, the structure of the meeting was explained and doubts regarding the instructions provided were clarified, then participants tried out the prototype for 45-minutes. Participants were allowed to ask questions regarding the content or the functionality of the DFMT. If students encounter errors in the tool, they were asked to take a screenshot and send it by email. In the end, participants answered the online questionnaire provided.

The goal of the online questionnaire was to elicit students' views towards the prototype within six dimensions: system quality, content quality, personalized learning, text-feedback quality, video-feedback quality, and benefits of the DFMT. The online questionnaire included 35 closed-ended items which could be answered according to a 5-point Likert scale, ranging from *strongly disagree* (1) to *strongly agree* (5). The questionnaire was adapted from the e-learning systems success (ELSS) developed by Y. S. Wang, H. Y. Wang, and Shee (2007). In addition to the six dimensions assessed, questions about the demographics details of the participants such as age, gender, nationality, and high school (secondary) degree were asked. At the end of the questionnaire, participants were asked for suggestions. See appendix B to find the questionnaire administrated. Moreover, the Grasple logs were collected and analysed. After the students' beta testing and its analysis were conducted, the second refinement of the prototype took place.

Beta Testing: Teacher Coordinator**.** Different from the students' beta testing, this test aimed to elicit teacher views about the functionality of the prototype, but also perceptions about the designed ideas, the quality of content, and its alignment with the curriculum of the course. The testing took place in a 90-minutes online meeting. First, the prototype of the DFMT was presented using a simulated frontend of what a student would see, known as the student' profile. Second, the additional features included in the teachers' profile such as the *monitor panel* was introduced to the teacher. Then, a structured interview assessing six dimensions of the digital tool (e.g., system quality, content quality, personalized learning, text-feedback quality, video-feedback quality, and benefits of the DFMT) was administrated. Finally, the teacher coordinator was asked for suggestions. See Appendix C to find the interview administrated. After the teacher beta testing and its analysis were conducted, the third refinement of the prototype took place.

4.3.4 Phase 4: Reflection.

The purpose of this phase is to reflect on the design, construction, and evaluation of the prototype while connecting ideas and constructs which might lead to new theoretical understandings. Organic reflections were made throughout the development of the three initial phases of the study. That means non-structured reflections took place in well-time breaks of the development of the research, for instance, at mealtime or at informal conversation with other researchers (McKenney & Reeves, 2019). After reflecting upon the findings, recommendations were made in other to enhance the possible integration of the DFMT to the Build-up Course Mathematics.

4. 4 Analysis

The data collected in this study included qualitative and quantitative data. Regarding qualitative analysis, the recordings from the dialogues obtained from the interviews and online professional meetings were transcribed using AmberScript, then coded using ATLAS.ti. The code analysis was segmented into utterances, in which an utterance was considered a distinct uninterrupted speaking turn by the participants or a written sentence. The utterances were categorised according to the research sub-question formulated in each phase of the study. To determine the interrater reliability, 13% of the utterances were coded by a fellow researcher, in which Cohen's Kappa was $\kappa = 0.86$. Transcribed dialogues were consulted for understanding or gaining insights into the results when needed.

Regarding quantitative data collected from the documents provided in the first phase and the questionnaire administrated in the third phase, analyses were executed on SPSS. The reliability of the original questionnaire was evaluated by assessing the internal consistency of the items representing each factor using Cronbach's alpha. The reliability of each factor was: system quality = 0.89, content quality = 0.91, and benefits of the tool = 0.95. In total, the reliability of the original questionnaire was 0.96.

4.4.1 Phase 1: Analysis of Practical Problem

This phase aimed to provide a characterisation of the Build-up Course Mathematics context. As proposed by McKenney and Reeves (2019), to obtain a better understanding of the named context, the problem and the context analysis were depicted as well as the characteristics of the stakeholders (e.g., practitioners and students).

Problem Analysis. To analyse the problem a deductive coding scheme consisting of three categories were used to classify the utterances: current situation, desired situation, and suspected causes of the current discrepancy (McKenney & Reeves, 2019). The utterances coded in the current situation described what occurred during the course on a daily basis, for example, "it seems that some of the students on the high end feel currently under-challenged". The desired situation referred to the expectations of practitioners about the students registered in the course, for example, "Getting them (students) soon enough at a level that we think is acceptable for the programme". Finally, causes of discrepancy reported practitioners' opinions about the possible causes of the problem experienced, for instance, “these high school high schoolers will not take math B, they will not take math D because they are told not to”.

Context Analysis. Similar to the problem analysis, a deductive coding scheme consisting of two categories were used to code the utterances: organizational and policy context, and educational context (McKenney & Reeves, 2019). First, organizational and policy context utterances were related to the extent to which the CreaTe and the Build-up Course Mathematics possess the autonomy to make changes. “I came up with the idea and I organized it in a way that I think is the best way to help our students” is an example of an utterance segmented in this code category. Second, the group of utterances in the educational context were linked to descriptions about the course curriculum, methodology and frequency. For example, “we do something with calculus, precalculus functions, differentiation and, uh, and trigonometry”. Additionally, the documents provided by the teacher complemented the analysis of the educational context. These documents encompass the syllabus of the course, tests and practice exercises.

The material context analysis referred to resources available such as infrastructure, software’s and other resources that were analysed using document analysis.

Characteristics of the students. To obtain a characterization of the students entering the CreaTe programme a document analysis was conducted. The characterization of the students includes nationality (Dutch, German, European. and non-European), gender, previous education (VWO, HBO, and International) and previous math education (math A, math B, math C and math D). Additionally, the failure rate and the percentage of first-year students attending the Build-up Course Mathematics were calculated. The characterization of the teacher coordinator is obtained from the code analysis interviews made in this phase.

4.4.2 Phase 2: Design and Development of a Solution

The main purpose of this phase was to develop a digital solution for the Build-up Course Mathematics that supports students’ performance. To achieve that, the design propositions and design requirements were first examined, then the construction of the solution took place.

Design Propositions. As suggested by McKenney and Reeves (2019), the designed propositions are theoretical understandings related to the context of the study. Therefore, a literature review on flexible learning pathways, personalised learning, adaptive items, and feedback was made and presented in the Theoretical Framework section of this report. Google Scholar was the main tool to search articles related to the topics previously mentioned. Forty-five articles were examined related to the words “flexible learning pathways”, “flexible learning in higher education”, “blending environments in high school”, “math education and technology integration", "math education and technology integration", "OER in tertiary education", "adaptive learning", "personalised education", "adaptive items in e-learning", "differentiation", "Grasple" and "feedback", etc.

Design Requirements. It referred to the exploration solutions derived from the analyses made in the previous phase (e.g., problem analysis and context analysis). Additionally, the boundary conditions and operational criteria were studied

Goal setting. The goal was determined through the analysis of the utterances coded as *desired situation* and the description of the *material context,* both derived from the analysis made in phase 1 (see section 4.4.1). Also, the theoretical understanding was considered to set the goal of the intended solution.

Boundary Conditions. The boundary conditions were assessed using deductive coding that categorised the utterances in two code categories: enablers and resistors. The purpose of analysing boundary conditions is to determine which factors will enable or hinder the intended change in the Build-up Course Mathematics. The utterances identified as enablers referred to statements reflecting acceptance of possible changes in the course. The following utterance is an example of it: "We (teacher coordinator and TA) reflect on the course(...) normally, we have a couple of meetings before the course starts and after the course is finalised". The utterances used as resistance were related to statements reflecting opposition to the intended change in the course. For instance, "so do as much as we can pen and paper and only use computer laptops for them to just do assignments, but not to do the mathematics for them".

Operational Criteria. Grasple's technical key elements and features were depicted into course structure (e. g, *learning objectives, lesson, exercises,* and *feedback*) and functionality.

Construction of the Prototype. The elements aforementioned were used to construct the prototype of the solution which contained few elements of the intended solution. Iterative cycles between design propositions and design requirements were made to develop the prototype of the solution.

4.4.3 Phase 3: Evaluation: Iterative Cycles of Testing, and Refinement

The aim of this phase was to elicit teachers' and students' perceptions of the DFMT build in the previous phase. Two types of testing (e.g., alpha and beta testing) were conducted in three different sessions.

Alpha Testing. The qualitative data obtained from this testing was coded using deductive coding. The coding scheme used includes two code categories: design solution and functionality. Utterances segmented into the design solution described the opinions stated by the e-learning specialist regarding the design ideas and their alignment with the design propositions (e.g., theoretical framework).

Functionality referred to utterances related to the prototype functionality such as "To avoid the 3-trial, so you just make a test (instead of 'homework') and then you put all those ideas in the test, and you will give the same name to it as soon as is best and you won't see the trial effect anymore".

Beta Testing: Students. This testing provided qualitative and quantitative data. The quantitative data was obtained from the Grasple logs, and the online questionnaire administrated. Grasple logs were used to assess students' performance in the DFMT based on three measures: number of exercises answered, number of correct answers and whether they completed the *subject* or not. The online questionnaire was constituted by six dimensions aiming to examine different aspects of the tool. First system quality assessed the overall functionality of the developed DFMT using five items. Second, seven items included in the content quality' dimension examined the quality of the *learning objectives*, *lesson* (math definitions and terminology) and *exercises*. Third, personalised learning evaluated the extent to which the DFMT fit the needs of each student using five items. Four, six items included in text-feedback quality's dimension assessed the quality of the explanations (e.g., cues and steps) provided by the tool in the orange or green boxes after an answer is given. Five, video-feedback quality examined the quality of the videos presented through six items. Finally, two items assessed the overall benefits of the DFMT. Appendix B shows all the items included in the online questionnaire. The quantitative data analyses were executed aided in SPSS, by calculating the descriptive statistics of the information obtained.

The qualitative data obtained from the suggestion box included in the questionnaire was coded using an inductive coding scheme which consisted of two categories: feedback and lesson. Feedback referred to utterances related to the information provided to students to track their progress, or the information displayed by the DFMT after the answer of an exercise was given. Lesson referred to the mathematical definitions integrated into the digital tool to the users before the exercises are displayed.

Beta Testing: Teacher Coordinator. The qualitative data obtained from this testing was coded using deductive coding. The utterances obtained from this testing session were classified into six categories: system quality, content quality, personalised learning, text-feedback quality, video-feedback quality, and benefits regarding the intended use of the digital tool. These categories are an adaptation of the ones suggested by Wang et al. (2007) to measure the success of e-learning systems.

System quality referred to the overall functionality of the tool, for instance, “I like the layout. That's nice. That's clear". Content quality related utterances about the quality of the *introduction of the subject* (i.e., learning objectives), *lesson* (i.e., mathematical definitions) and *exercises* presented in the DFMT in terms of clarity, sufficiency, and relevancy as well as its alignment with the curriculum of the course. To illustrate, “*Learning objectives* and the definitions seem sufficient”. The utterances classified in the personalised learning category expressed opinions regarding the number of exercises presented, their level of difficulty and learning modalities given, for example, “It's a good thing you will not get an endless number of exercises that you have to do”. Text-feedback and video feedback referred to the clarity and sufficiency of the feedback displayed by the tool once the student attempts a question. For instance, “I think the videos are kind of clear and clean” and “I think the feedback is sufficient. I think it's pretty much like the feedback that they would get from my teaching assistants or from me”. Benefits of the tool referred to the possible impact the intended use of the tool would have in the course. To illustrate, “It will help students because it's not just practising, but it's also in case of problems getting proper feedback”.

Different from the beta testing conducted to the students, the teacher version of the testing also examined the viability of the intended use of the digital tool in the Build-up Course Mathematics. Therefore, utterances in this category described teacher opinions about factors that enable or hinder the intended change. For instance, “I think the tool is great, I mean, it's better than what we had, and it has it has some potential, especially with the sale of feedback and with the thing that you could kind of go through the material quicker than with the other one” represented an enabling factor. While “To create a branching tree for each topic is a little bit harder because then you have to know how students work on exercise and it requires some experience in what goes wrong" expressed possible factors that hinder the change.

4.4.4 Phase 4: Reflection

The purpose of this phase was to describe how the DFMT can be improved to enhance its intended use in the Build-up Course Mathematics. The data collected through the previous three phases served to reflect upon the design solution integrated into the Digital Flexible Math Tool.

5. Results

5. 1 Phase 1: Analysis of Practical Problems

5.1.1 Problem Analysis

To accurately describe the problem experienced by the CreaTe programme director, the teacher coordinator, and the teacher assistants in the Build-up Course Mathematics, the current and desired situation were inferred from the interviews as well as the causes of the discrepancy. Regarding the current situation, participants indicated that the level of the students attending the course varies dramatically. There are some students with notorious low math literacy, but also students who feel under-challenged by the course. For instance, the programme coordinator commented: "it seems that some of the students on the high end feel currently under-challenged", "they (students) are behind, they don't have as much knowledge as some of the other ones", "students with such a broad range of math aptitude or math knowledge". Additionally, the teacher coordinator stated: "That's the group of students having a sufficient background in mathematics, and a group of students, um, who need attention". "The level of the students variates a lot" was the statement of one of the teacher assistants.

Regarding the desired situation, respondents pointed out that the aim of the Build-up Course Mathematics is to prepare first-year students for the advanced math courses included in the curriculum of the programme. That means, boosting their math knowledge and skills that allow them to understand the content of the advanced courses, but also provide instruction that challenges all the students. For instance, one of the teacher assistants reported that “So learning the formulas everybody can learn them by heart, but students should be able to come to that state of mind, where they think in a logical way”. The programme director commented “Getting them soon enough at a level that we think is acceptable for the programme" and “So we have to think about ways to challenge every student at his or her own level”. The teacher coordinator pointed out: “So what we hope, of course, that it might also help them, um, to move on with the mathematics, to trigger them a little bit and to give them insight and their own skills, but then also what they're missing”.

In terms of the causes of discrepancy, the participants mentioned several reasons that might explain the lack of math literacy and the diversity of student body. The first reason referred to the elimination of entry requirements adopted by the programme to attract more students. To illustrate, the teacher coordinator stated “The students that we would attract, it should also be a bit different from the other programmes at the university, so we thought that if we come up with the same requirements, we will probably get less the same students. And we will miss, uh, talented students that might not be just good in mathematics and physics to start with but have really other tell us that could be very useful for our particular programme”.

The second reason was related to internationalisation, for example, the programme coordinator underlined “we have a significant proportion of internationals coming from a wide range of nations”. And one teacher assistant explained “So they are more homogeneous in their background because, of course, their education was in one country. So, it's easier to tackle their problem, but when there are many internationals, their math levels are all over the place", and "So I think that they needed special help and really to devote more time to help them individually because all of them came from different high schools. So, and not just the level of knowledge, but how to approach a problem, which was it depends on the country and the educational system that they are going that they are coming from. Some of them are more theoretical theory-based than some of them do it in the other way."

Third, the lack of math literacy of the upcoming students is explained by the programme director as the inadequacy of guidance for students regarding the courses they are advised to take. To illustrate, "these high school high schoolers will not take math B, they will not take math D because they are told not to". Another reason provided by the respondents to explain the low performance of the student was the lack of confidence, for example, the programme coordinator argued "we have a number of students entering the programs who don't feel very safe on that on that subject", and "are students who don't know the class and they don't like math. And they were told all their lives that they are not good at math". Also, the teacher coordinator inferred "There are students who don't like math because they were told all their lives that they are not good at math".

Lastly, one of the teacher assistants assured that the performance of the students is negatively influenced by the language of instruction: English. To illustrate, "But if the students do not know the terms in English, then they simply cannot complete the intake exam. So, they get bad grades. The only problem they had was simply the terms in English".

5.1.2 Context Analysis

Context of the CreaTe Programme. This programme offered by the University of Twente is a three-year bachelor programme that aims to train students to develop technological solutions that positively influence people's life. It combines computer science and electrical engineering skills with social and entrepreneurial components that allow students to design solution that benefit society. Due to the STEM nature of the programme, the curriculum includes six courses of mathematics throughout the programme which requires students a strong foundation in math competencies. As a part of the curriculum, Build-up Course Mathematics was created to support first-year students to boost their math skills and prepare them for advanced math courses.

Context of the Build-up Course Mathematics. The course is tailored to the first-year students of the CreaTe programme with the lowest scores in the math diagnostic test conducted at the beginning of the programme. However, the flexible measures adopted by the programme allow students to decide whether to register in the Build-up Course Mathematics or in the simultaneous course which is tailored to higher-level students. The course is taught in one week, where from Monday to Thursday the instruction combines lectures, practices, and self-tests. On Friday, a Q&A session is scheduled and then the final test takes place. The final grade of the course is a combination of assignments grades, attendance, and test grade.

In terms of the organizational and policy context of the course, the teacher coordinator and the teacher assistants highlighted the autonomy to make changes and decisions within the course. To illustrate, “I came up with the idea and I organized it in a way that I think is the best way to help our students”, “The teacher assistants take the lead in the explanations, theoretical parts, suggesting content". Regarding the curriculum and the content of the course are described in Appendix D.

Grasple. In terms of the material context, it was found that the University of Twente uses Grasple as the online learning environment in the context of math education. Grasple is 'a curated repository for an open educational resource on mathematics and statistics' (Gillebaart & Bellinga, 2018). Grasple is a unique topic-oriented platform where teachers and students can find, edit, and share learning materials about statistics, basic mathematics, calculus, and linear algebra (Host et al., 2020; Gillebaart & Bellinga, 2018). Currently, Grasple is used in most of the mathematical courses in the Math Line of the bachelor programmes offered by the UT. Its use is in line with the agenda of the Dutch Minister of Education for Higher Education set in 2015 which encourage Dutch HEI to share educational materials and recognise MOOCs and OER (Ministry of Education Culture and Science, 2015).

5.1.3 Characteristics of the First-Year Students of the CreaTe Bachelor Programme at the University of Twente.

The information gathered from the document analysis provided a detailed explanation of the first-year students of the CreaTe programme from 2016 to 2020. 65% of the entering students are male. Regarding students' nationality, 76% of the students are Dutch, 16% are European (non-Dutch), and 8% are non-European. Regarding students' pre-education, 70% of the students hold a VWO degree, only 2% of the student have an HBO diploma, and 23% have an international degree. Regarding the course of mathematics taken in high school 29% of the students took math A, 56% of the students took math B, 13% took math B and D, only 1% of the students took math C. The previous information only applies to students who have a Dutch high school diploma. On average 120 students enter the CreaTe programme since 2016, approximately, 35% register to the Build-up Course Mathematics with a 79% of passing rate.

5. 2 Phase 2: Design and Development of a Solution

5.2.1 Design propositions

The design propositions are presented in the Theoretical Framework of this report (see Chapter 2).

5.2.2 Design requirements

Goal Setting. In the interviews conducted in the previous phase, the respondents indicated that they hope to provide students registered to the Build-up Course Mathematics with the necessary math knowledge and skill that allow them to understand and improve their performance in the advanced math courses of the curriculum. They hoped to "Getting them (students) soon enough at a level that we think is acceptable for the program". Also, they expressed the desired to provide instruction that addresses the needs of all students despite their academic background. To illustrate, "it's important to challenge students at their own level". Using the theoretical understandings, it was found that the Build-up Course is the reflection of the FLP measures adopted by the UT. Therefore, combining teachers desired, theoretical understandings and the material context depicted from the previous phase, it is concluded to develop a DFMT in Grasple.

Boundary Conditions. The boundary conditions aimed to explore factors that enhance or hinder the intended change of introducing the digital tool in the course. Regarding enablers, the autonomy of the teacher coordinator could facilitate the intended change. For example, the teacher coordinator stated that he is the main course' designer and highlighted the autonomy he has in terms of the decision-making process. In literature, this is named as open organizational climate which leads to a positive effect on teachers' performance (Raza, 2010; Lee, Dedrick, & Smith, 1991). The teacher coordinator underlined the teamwork between him and the teacher assistants as well as the reflection process conducted at the end of the course. For instance, “We (teacher coordinator and TA) reflect on the course(...)normally we have also we have a couple of meetings before we start, and we have meetings after the course”. The study of Dee, Henkin, and Singleton (2006) underlines that teamwork among teachers has a positive effect on the organization since it increases teachers’ commitment, empowerment, and ownership. Van der Bossche and Beausaert (2011), assured those reflective behaviours are highly beneficial at the organizational level since reflective practitioners generate new understandings of their practice promoting continuous learning cycles.

Another enabler is the use of Grasple as a platform to develop the digital tool because it is known and previously integrated by the UT. The study of Lin, Ho, Sadiq, and Orlowska (2002) assures that the integration of technology in learning environments allow teachers to monitor students, share knowledge and enhance collaborative work, while students have more control over their learning process. Additionally, since Grasple has been already integrated into the UT, support channels for teachers and students are available which according to the study of Keengwe et al. (2008), the provision of technical support is essential to facilitate the integration of digital tools in the classroom.

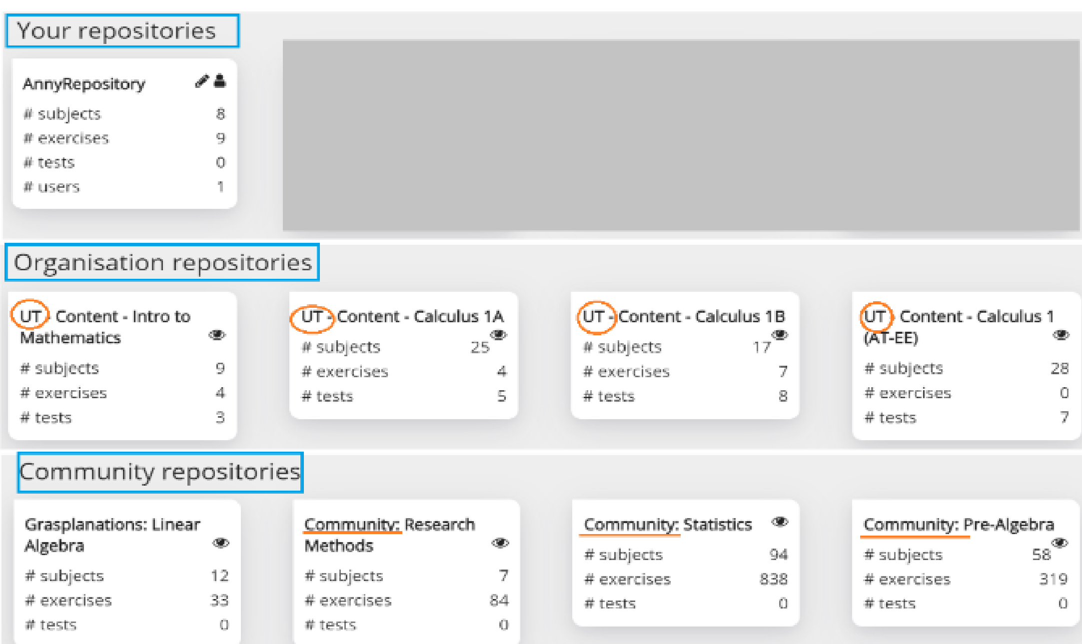
Regarding resistance to the intended change, respondents showed possible scepticism of the integration of technology in the classroom. For example, “We want our students to think, so no calculators, graphical calculators, or electronic devices”. Also, one of the teacher assistants commented, “Before, we used ‘MyLabPlus’ (…) we stopped its use because it was only available in English, there were many exercises repeated, and the immediate feedback only verified whether the answer was correct or not”. These statements are consistent with the study of Keengwe, Onchwari, and Wachira (2008) who explained that teachers resist the use of technology in the learning environments due to the lack of technology literacy, appropriate training, or the use of unreliable digital tools.

Operational Criteria. As stated in the goal setting, the platform used to develop the DFMT is Grasple (see section 5.1.2 for a detailed description of Grasple). The following key elements were found essential for the development of the Digital Flexible Math Tool.

Repositories. Are the space where the (pre-made) exercises can be found. There are three types of repositories: organisational repositories (i.e., material created by the University of Twente members), community repositories (i.e., curated content created by the community of Grasple), or personal repositories (i.e., content created by the user) as shown in Figure 3.

Figure 3

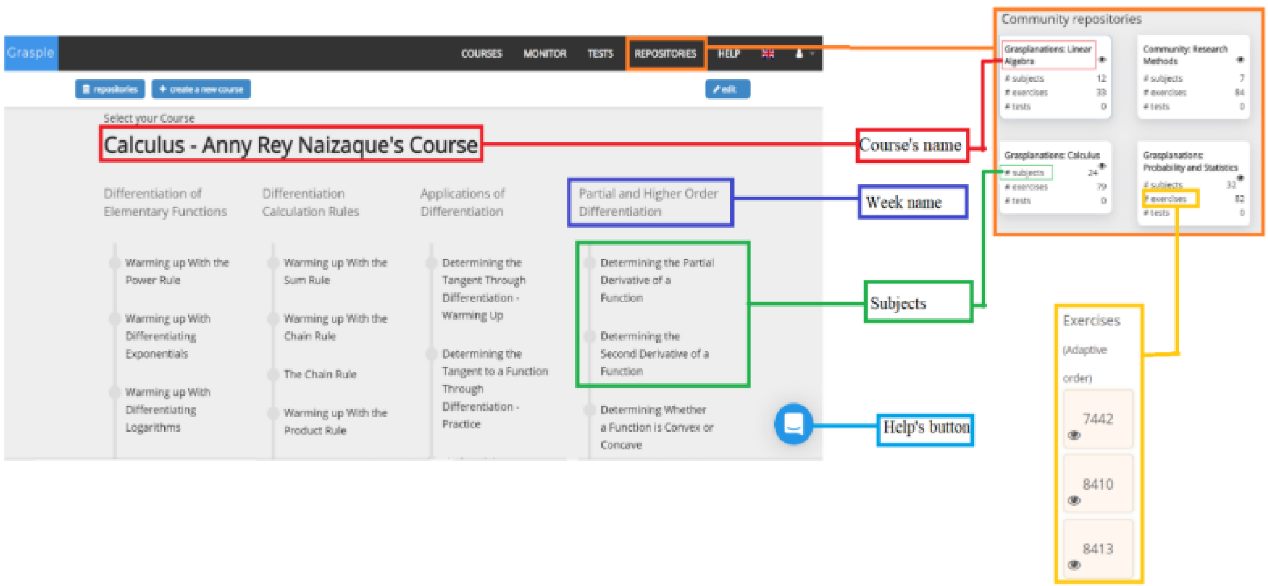
Screenshot of the Repositories Found in Grasple Under Teacher’s Profile.



Courses. It is where material can share with the students and their progress can be monitored. Courses usually contain several *subjects* presented according to the curriculum, usually per week. Teachers or e-designers can merge material from repositories into the course (see Figure 4).

Figure 4

Screenshot of the Layout of Grasple's Key Elements



Subject. Topics assessed are placed into *subjects*. A *subject* is constituted by the *introduction of the subject*, *lessons*, and *exercises*.

Exercises. Grasple allows three different ways to present the exercises: (1) *fix order* which means students are required to do all exercises included in a *subject* to continue with the next one, (2) *adaptive order* where the students need to correctly answer 5 exercises randomly selected to pass the *subject*, and (3) *conditional logic* which the question delivered depend on the previous answers given by each specific student. In addition, each question can be formulated in different modalities (e.g., multiple-choice, numeric, one word-answer, and math/equation).

Attempts. Grasple allows students two have three attempts per exercise.

Feedback. Grasple provides three types of feedback: (1) provides information about how to improve student's performance. As shown in Figure 5, that information can be placed in two different boxes. The information included in the green box is displayed once the exercise is answered correctly or at the third attempt. The information of the orange box is displayed when the exercise is incorrectly answered in the first two attempts; (2) allows students to track their progress within a *subject*. Information about the number of *subjects* completed within a course is given as well as the status of each *subject* (see Figure 5); (3) allows the teachers to monitor students' progress in terms of students registered to the course, students' *subject* mastery, and correctness of an item. Information about the number is shown in Figure 6.

Figure 5

Screenshot of Feedback Provided to Students

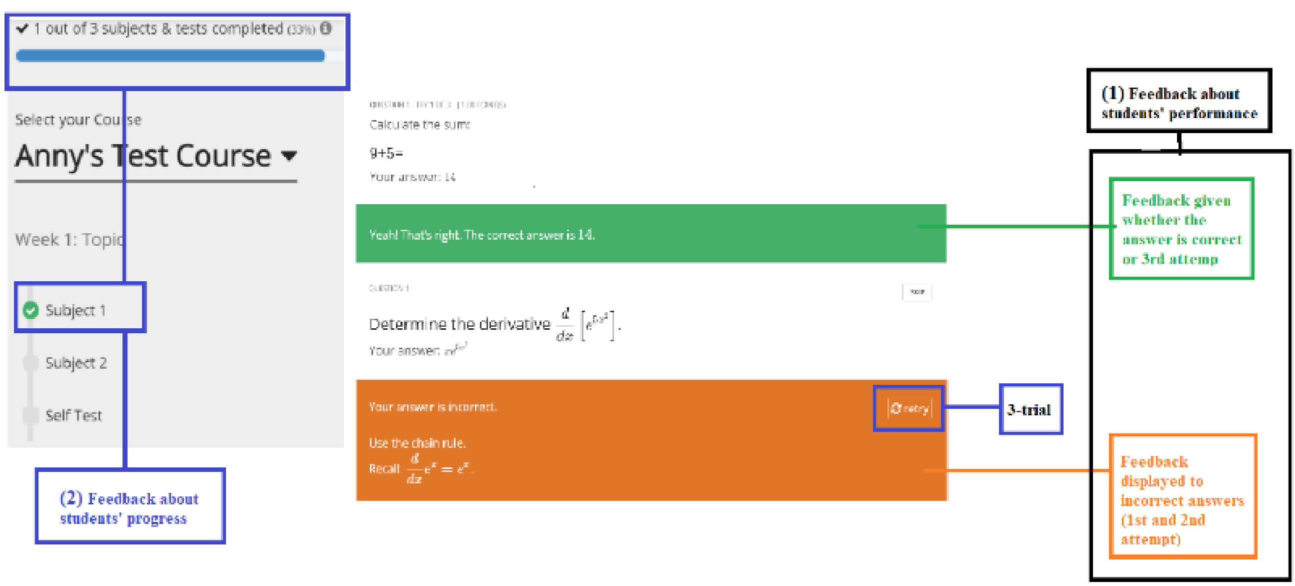
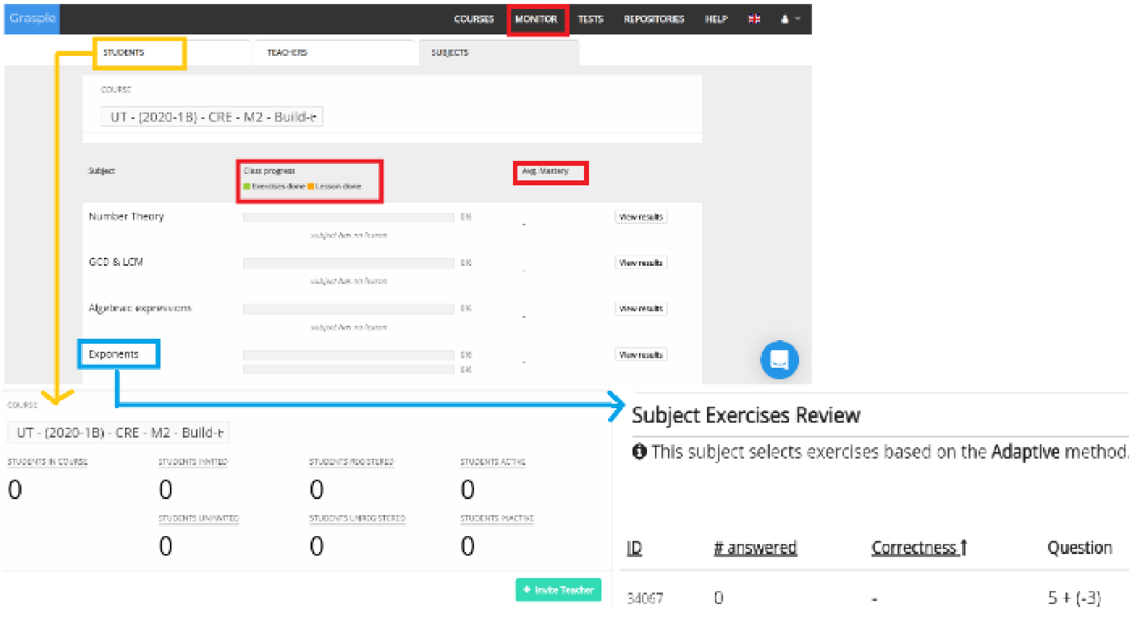


Figure 6

Screenshot of Feedback Delivered by Grasple to Teachers



5.2.3 *Construction of the Prototype of the Digital Flexible Math Tool.*

The prototype developed in this study it is what Tripp and Bichelmeyer (1990) defined as rapid prototype for instructional design which its construction and modification is done in a short period of time. Therefore, the prototype included only a few components of the desired solution. The construction of the prototype is made in an iterative cycle between the design proposition and design developed in a decision-making process explained below.

First, the decision of the which components to be developed was made. Using the curriculum of the course Build-up Course Mathematics, it was decided to use *Property of Exponents* as the only *subject* to be developed in the prototype. The *Property of Exponents* was then divided into three subtopics (1) *Product Property*, (2) *Power Property*, and (3) *Quotient Property*.

The second decision made was the selection of *conditional logic* to present the exercises in the prototype of the Digital Flexible Math Tool. The selection of a *conditional logic* implied the creation of an adaptive branching tree with a 15-item flexi-level. The items are classified into six levels of difficulty where the initial level is n, the lowest level is $n - 2$, and the highest level is $n + 3$. The adaptive nature of this branching tree means that even though all students start with the same item of level n, there are multiple paths they follow, the number of questions needed to move to the next subtopic depends on the student's performance, in fact, there are some questions students may never try (see Figure 7). However, the minimum number of items needed to pass to the next topic is four, that is, answering correctly four consecutive items allow students to move to the next subtopic. In the case students have a mix of answers (i.e., correct and incorrect), they need to reach and answer correctly one item of level $n + 3$ to pass to the next subtopic. In contrast, answering incorrectly all the items, students are directed into a video that explains the item $n - 2$. Also, whenever the students answer incorrectly three items (i.e., consecutive, or not) they find a video with a detail explanation in the feedback box.

Once the genetic branching tree was defined, the creation of items took place. Due to the subtopic division, 15-items are created per subtopic. Each item was classified into a level based on the math competencies assessed. Tables 2, 3 and 4 presented below show the items created its categorization per level and its identification number in Grasple.

Figure 7

Genetic Branching Tree Developed to Set the Items in Grasple

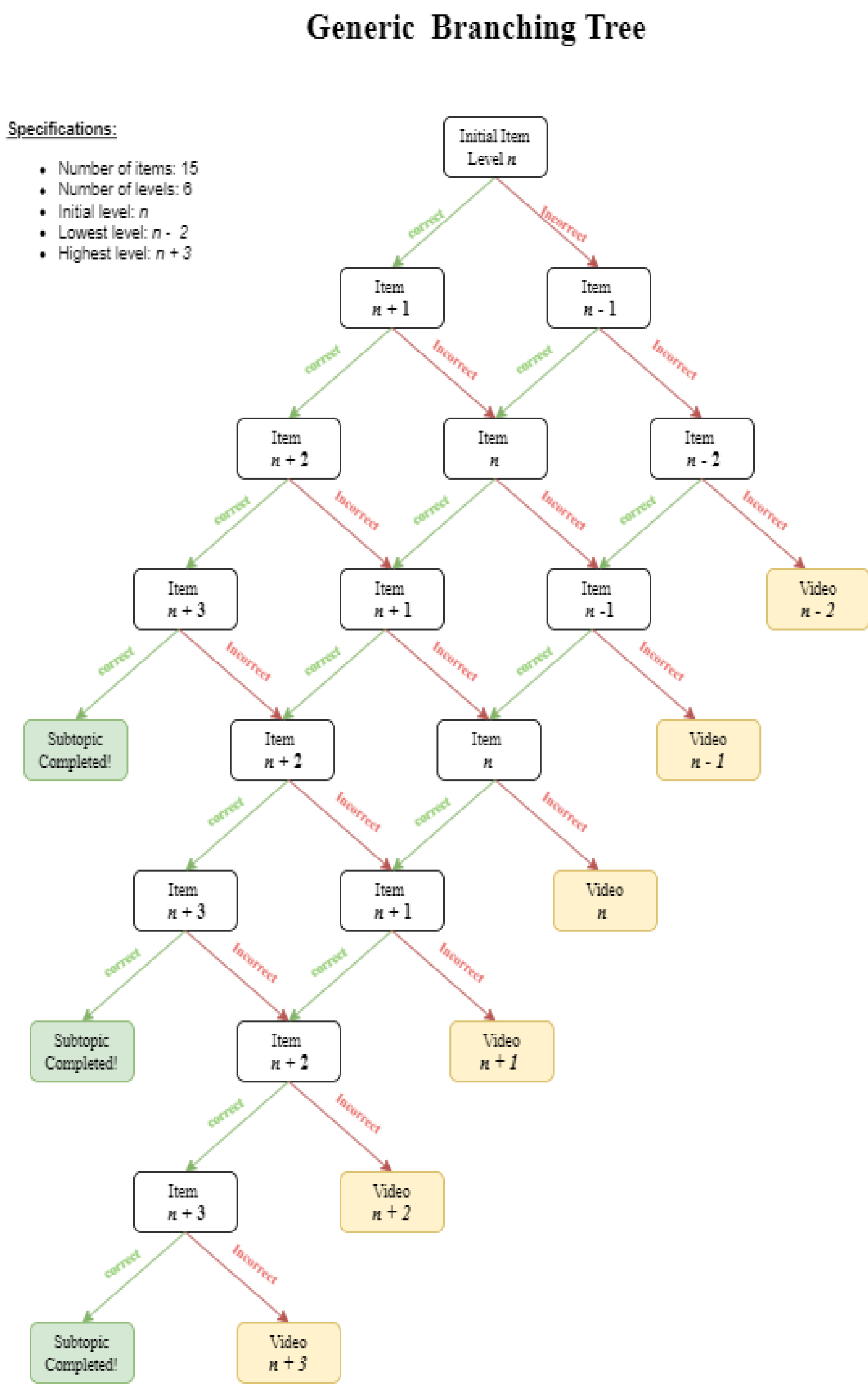


Table 2

Product Property of Exponents: Items vs Competencies Assessed

Product Property of Exponents			
Item level	**Math Competencies**	**Item**	**Item ID in Grasple**
$n-2$	PPE in extended form	$2^5 * 2^3$	38711
$n-1$	Variable base: one Exponents: natural (excluding one) #of terms: 2	$a^4 * a^8$ $x^2 * x^4$	38710 38716
n	Coefficients: natural (excluding one) Variable base: one Exponents: natural (excluding one) #of terms: 2	$2x^4 * 5x^3$ $10y^2 * 3y^7$ $12z^5 * 11z^6$	37839 38713 38718
$n+1$	*Product Property of Exponents* Coefficients: integers (excluding one) Variable base: one or two Exponents: natural #of terms: 3 *Other competencies:* Multiplication of integers	$-6x^2 * -3xy^4$ $(7x^2y) * (-2x^2y^4)$ $(-125p^{37}q^{98}) * (3p^{12}q)$	31840 38715 38720
$n+2$	*Product Property of Exponents* Coefficients: natural Variable base: two or more Exponents: integers #of terms: 3 *Other competencies:* Addition of integers Multiplication of integers Negative Property of Exponents	$-9xy^2 * 6x^2z^3 * 4xy^3z^{-4}$ $v^{-28}w^{-3}z^2 * -5v^2w^7z^4 * -4wz^{11}$ $-7p^9q^{-12} * 8p^{-3}q^7r * 11pq^4r^{-22}$	38712 38717 38721
$n+3$	Coefficients: natural (excluding one) Variable base: one or two variables Exponents: natural #of terms: 3 *Other competencies:* Multiplication of integers Zero Property of Exponents Negative Property of Exponents Distributive Law	$-6x^2(2x^3y^4 - 9x^{-2}y^{-1} + z)$ $-2w^3y^6z^3(-4wz^{-4} + 6w^{-2}y + wy^{20}z^{-3})$ $-2p^7q^5r^{-2}(41p^5qr - 3pq^{-2}r^2 + 32p^{20})$	38714 38719 38722

Table 3

Power Property of Exponents: Items vs Competencies Assessed

Power Property of Exponents			
Item level	**Math Competencies**	**Item**	**Item ID in Grasple**
$n-2$	Base: numerical (natural) Exponents: natural	$(7^2)^3$	38725
$n-1$	Base: one variable Exponents: natural and rational	$(y^4)^{13}$ $(x^{52})^{1/4}$	38724 38746
n	Numerical base: natural and rational Base: one variable Exponents: natural and rational	$(9x^2)^3$ $(64n^{42})^{1/2}$ $\left(\frac{5}{3}w^7\right)^2$	38723 38728 38748
$n+1$	*Power Property of exponents* Numerical base: integers Variable base: two or more variable base Exponents: integers and rational *Other competencies:* Multiplication of signed numbers Negative Property of exponents	$(-6xy^5z^{-2})^3$ $\left(4^{-1}p^{\frac{-4}{3}}q^8r^{-9}\right)^{-3}$ $(5^{-1}u^4v^3)^{-4}$	38726 38745 38749
$n+2$	*Power Property of exponents* Numerical base: integers and rational Variable base: two Exponents: integers and rational *Other competencies:* Order of Operations' rule Addition of integers Multiplication of integers (signed numbers) Negative Property of exponents Product Property of exponents	$\left(\frac{5}{4}x^6y * 3^2x^4y^{-\frac{2}{3}}\right)^2$ $\left(\frac{2}{15}m^{\frac{-11}{2}}n^{-7} * 5^2m^6n^{-9}\right)^2$ $-\left(5vw^{-12} * \frac{1}{5}v^{1/3}w^8\right)^{3/4}$	38727 38747 38753
$n+3$	*Power Property of exponents* Numerical base: integers and rational Variable base: two Exponents: integers and rational *Other competencies:* Order of Operations' rule Addition of integers Multiplication of integers (signed numbers) Negative Property of exponents Zero Property of exponents Product Property of Exponents	$\left((3a^4b^2c)^6 * \left(-\frac{1}{3}a^5b^{-7}c^{-2}\right)^3\right)^{\frac{1}{3}}$ $((4x^5y^8z^7)^2 * (xy^{-3}z^{-6})^{-4})^{\frac{1}{2}}$ $\left((u^{16}v^3w^2)^{-\frac{1}{4}} * \left(\frac{1}{64}u^2v^{-\frac{5}{4}}w\right)^2\right)^{\frac{1}{4}}$	38736 38751 38754

Table 4

Power Property of Exponents: Items vs Competencies Assessed

	Quotient Property of Exponents		
Item level	**Math Competencies**	**Item**	**Item ID in Grasple**
$n-2$	Base: one numerical base Exponents: natural (excluding one)	$\frac{5^3}{5^2}$	38771
$n-1$	Base: one variable Exponents: natural (excluding one)	$\frac{x^{35}}{x^{20}}$ $\frac{z^{113}}{z^{43}}$	38766 38777
n	*Quotient Property of Exponents* Coefficients: without simplification Base: one variable Exponents: integers and rational (including one) *Other competencies* Subtraction of rational numbers	$\frac{5z^2}{3z^{\frac{3}{4}}}$ $\frac{7n^3}{2n^{\frac{1}{3}}}$ $\frac{3p^6}{10p^{\frac{1}{4}}}$	38755 38770 38779
$n+1$	*Quotient Property of Exponents* Coefficients: without simplification Base: two variables Exponents: rational (including one) *Other competencies* Addition/subtraction of rational numbers (signed numbers) Negative Property of Exponents	$\frac{5x^{10}z^{-1}}{6x^{-7}z^{\frac{3}{4}}}$ $\frac{7n^{\frac{1}{2}}m^{-6}}{3n^{\frac{1}{-3}}m^5}$ $\frac{4p^{\frac{5}{2}}q^{-7}}{9p^{-1}q^{-5}}$	38765 38776 38781
$n+2$	*Quotient Property of Exponents* Coefficients: with simplification Base: two variables Exponents: integers *Other competencies:* Order of Operations' rule Addition/subtraction of integers numbers Multiplication of integers (signed numbers) Negative Property of Exponents Zero Property of Exponents Product Property of Exponents	$\frac{9x^2y^{-4} * 2x^{-2}y^{-1} * 2y}{6x^3y^2}$ $\frac{3n^3m^{-18}p^{-5} * n^7m^9p^{-20}}{81n^{-10}mp^{-25}}$ $\frac{13u^{-4}vw^{-7} * 3u^{-8}v^9w^2}{18u^{12}v^3w^{-5}}$	38767 38778 38782
$n+3$	*Quotient Property of Exponents* Coefficients: with simplification Base: two variables Exponents: integers *Other competencies:* Order of Operations' rule Addition/subtraction of integers numbers	$\frac{(3x^2y^{-4} * 2x^{-2}y^{-1} * 2x^3y)^2}{30x^6y^{-7}}$ $\frac{(16n^3m^{-19}p^{-5} * 2n^7 4p^{-20})^{\frac{1}{5}}}{60n^{-2}m^5p^{-5}}$	38773 38780

Multiplication of integers (signed numbers) Negative Property of exponents Zero Property of Exponents Product Property of exponents	$\left(\frac{6u^8v^{-4}w^{-9} * 3u^6v^{-2}w^{-1}}{18u^{-14}v^3w^{-10}}\right)^{-3}$	38786

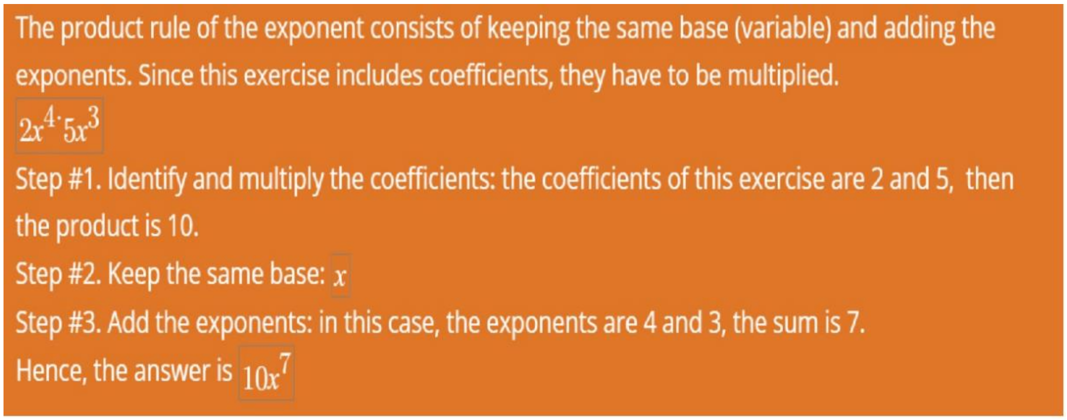
In total, forty-five items were created and place in the corresponding branching tree (See Appendix E). Due to the operational criteria of Grasple, students navigate first in the branching tree of the *(1) Product Property of Exponents*, then items of *(2) Power Property of Exponents* are delivered, finally, items of *(3) Quotient Property of Exponents* are asked. The *subject* is considered complete if users reach and correctly answer an item of the level $n + 3$ of the subtopic (3).

The last decision made is related to the provision of feedback. As mentioned previously, Grasple allows to include information that helps students to improve their answers. Therefore, it was decided to provide the elaborated feedback in the orange box. That means, the definition of the topic assessed, and the detailed step-by-step solution of each item were included in the orange box (see Figure 8). As shown in Figure 7, video-feedback was included in the orange box in case the student answer incorrectly three items. In total, 18-videos were created where each subtopic included six videos. The video-feedback contains the step-by-step solution of the item.

First Version of the Prototype. Once the decision-making process was finalised, the solutions decisions are integrated into Grasple. The prototype is constituted by three core elements, *introduction to the subject*, *lesson*, and *exercises*. First, the users find the course map as shown in Figure 9. Then, the *introduction of the subject* which contains the learning objectives is presented (see Figure 10). The *lesson* includes the mathematical definition of the topic chosen (See Figure 11). Finally, the *exercises* are presented to the students.

Figure 8

Screenshot of One Example of the Elaborated Feedback Created and Provided



The product rule of the exponent consists of keeping the same base (variable) and adding the exponents. Since this exercise includes coefficients, they have to be multiplied.

$2x^4 \cdot 5x^3$

Step #1. Identify and multiply the coefficients: the coefficients of this exercise are 2 and 5, then the product is 10.

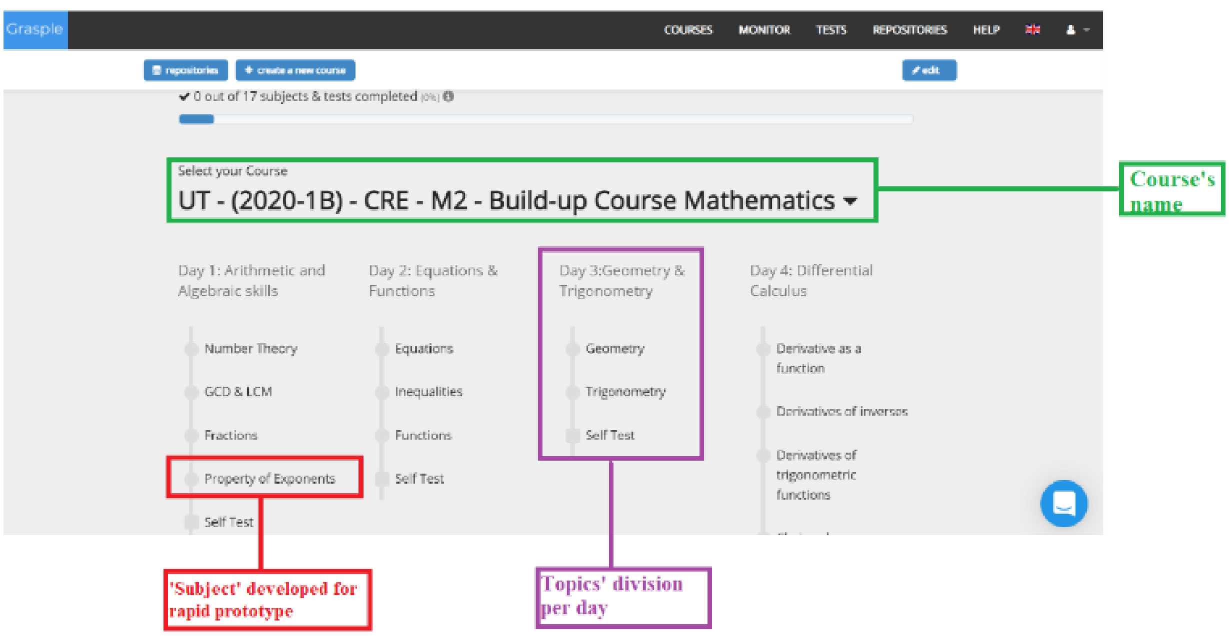
Step #2. Keep the same base: x

Step #3. Add the exponents: in this case, the exponents are 4 and 3, the sum is 7.

Hence, the answer is $10x^7$

Figure 9

Screenshot of the DFMT Initial Menu



Note. Although the prototype includes only one *subject* (topic), the other topics are added to the digital tool menu, so users can see how the real environment will look.

Figure 10

Screenshot of the Learning Objectives Created in the DFMT

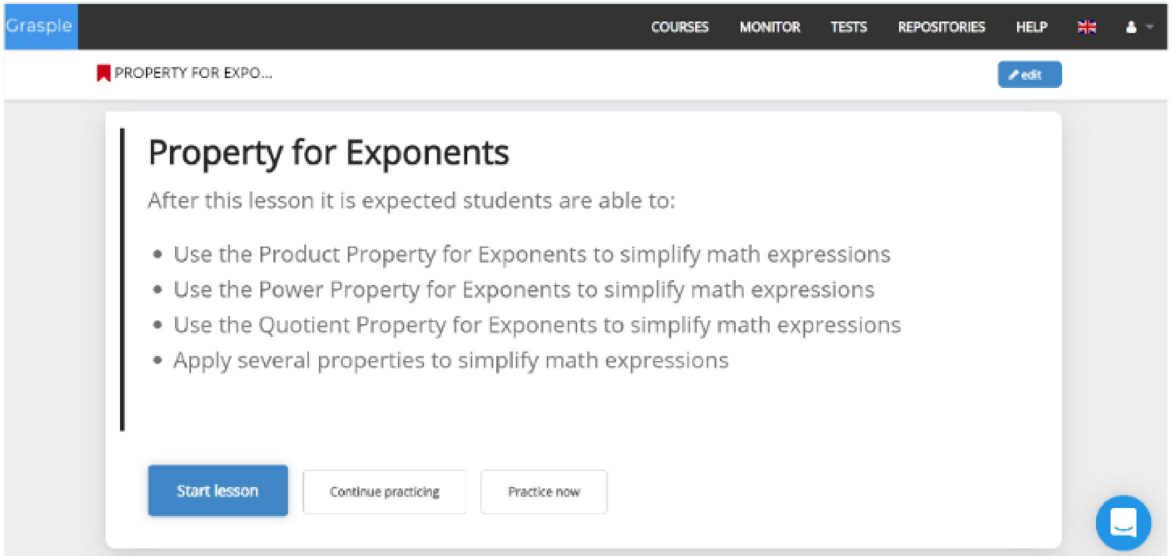
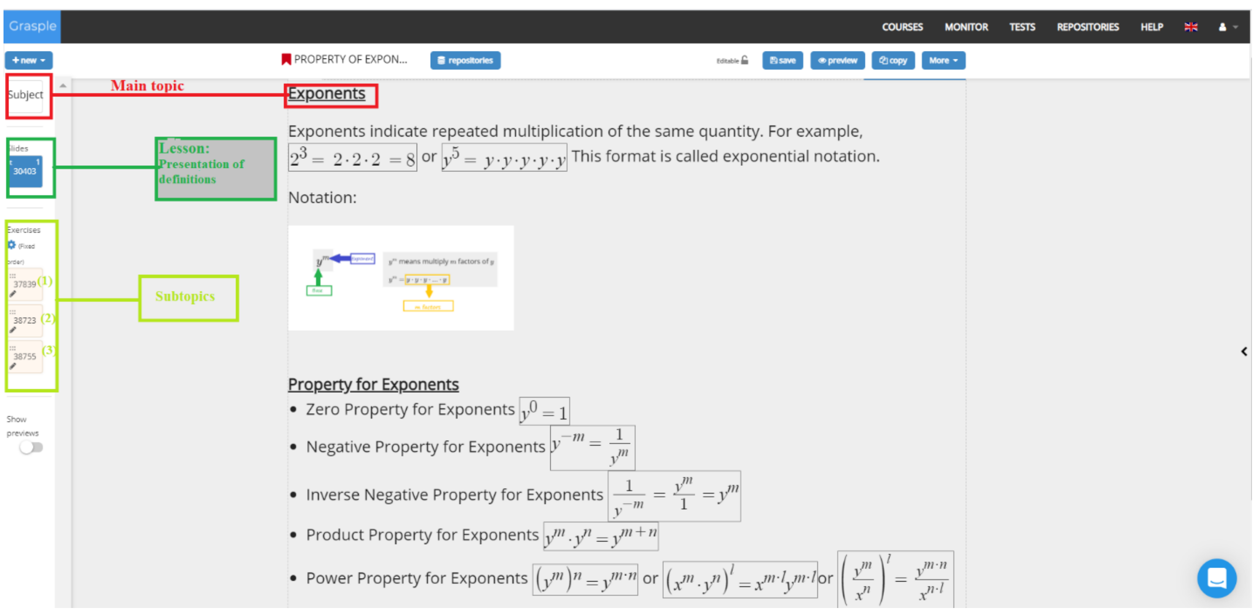


Figure 11

Screenshot of the Lesson Created in the DFMT



5. 3 Evaluation: Iterative Cycles of Testing, and Refinement

The main goal of this phase was to elicit the perception of students and teachers of the DFMT. Nevertheless, conducting alpha testing was necessary to evaluate the design solution integrated into the Digital Flexible Math Tool and its alignment with the named context.

5.3.1 Alpha Testing and Refinement

Alpha Testing. The design solution included in the prototype as well as its functionality were assessed in this testing. In the interview, one respondent expressed their concern regarding the high amount of information provided in the feedback box, which could hinder students' knowledge acquisition. To illustrate, "I just have one question, and that's to do with the feedback that you give to the questions, and I saw that when you give the feedback when people do questions wrong, you're explaining the questions that they have in front of them. And I'm wondering, how much did they learn from that one and try again because you're actually giving the answer away to the students".

Regarding the prototype functionality, issues about the use of embedded videos were reported and then fixed using Grasple manuals provided by the e-learning specialists.

First Refinement. Regarding the excessive amount of feedback reported by the respondents, it was found that e-learning specialists' opinion is consistent with the study of Sweller et al. (1998) who underlined that the provision of worked examples reduces students' effort to understand and develop problem-solving skills. Therefore, it was decided to reduce the amount of information. Paas, Renkl, and Sweller (2003) assured that the reduction of extraneous cognitive load (i.e., the manner in which the information is presented) enhance learning. Particularly, the solution of the exercise was eliminated, but the step-by-step guidance was maintained. With this change, the students are required to generate their own answers. The decision about providing general steps is supported by the study of Sweller et al. (1998) who affirms that steps enhance students' deductive skills. Also, the definition (in words/text) of the topic (i.e., Product Property of Exponents) given in the first draft version was eliminated. Instead, a question was included aiming to give the students cues regarding which Property of Exponents they should use to solve the problem. The use of questions in e-learning math environments is supported by Kramarski and Gutman (2006) who found that questioning improves students' performance. Please see Figure 12 to see the new version of the feedback provided.

Figure 12

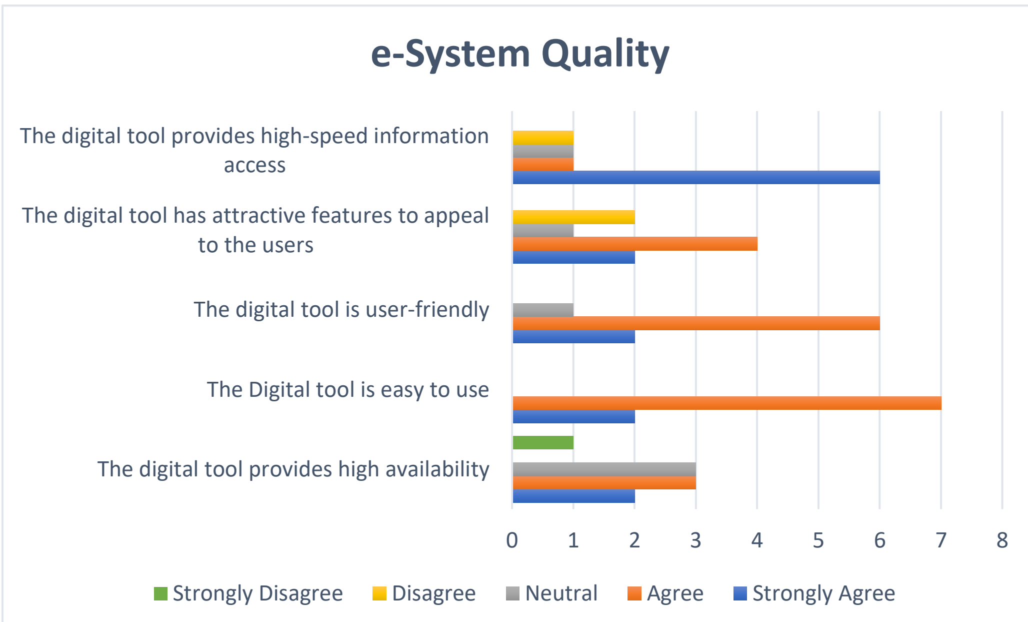
Screenshot of the Refined Version of Feedback of one Item

5.3.2 Beta Testing: Students and Refinement

Beta testing. The purpose of conducting this testing was to see how relevant and usable the students perceive the prototype developed. Nine participants tried out the digital tool, however, only four of the participants completed the *subject* within the given time. The number of exercises answered ranged from 6 to 21 items (M = 13.78, SD = 4.29). The number of correct answers ranged from 5 to 11 (M = 6.22, SD = 3.01). Regarding students' perceptions of the digital FPL math tool developed, six dimensions were assessed. Figure 13 contains the responses which assess the quality of the e-system in terms of its functionality. On average, 78% of the responses indicated positive perceptions of the DFMT. However, during the intervention, four errors were encountered. The errors pointed out technical issues such as giving the correct answer but being marked as incorrect by the tool (or vice versa) and missing information needed to deliver the answer. See Appendix F for detailed information about the errors.

Figure 13

Students' Responses Regarding Quality of the DFMT



Content quality was a dimension included in the questionnaire which evaluated the quality of the learning objectives included in the *introduction of the subject*, the *lesson* (e. g., definition of the Property of Exponents and terminology) and the *exercises* presented in the digital tool. Figure 14 shows that 64% of the participants reported positive perceptions of the quality of the content. However, when participants were asked if the digital tool provides information at the right time, most of the students reported negative views in this matter. In fact, 36% of the utterances obtained from the suggestion box, indicated that participants would like to access the *lesson* once the exercises are displayed. For instance, one student commented: "Maybe make it possible to go back to the slides during the exercises or have them as a menu next to the questions when making the exercises?".

Figure 14

Students' Responses Regarding Content of the DFMT

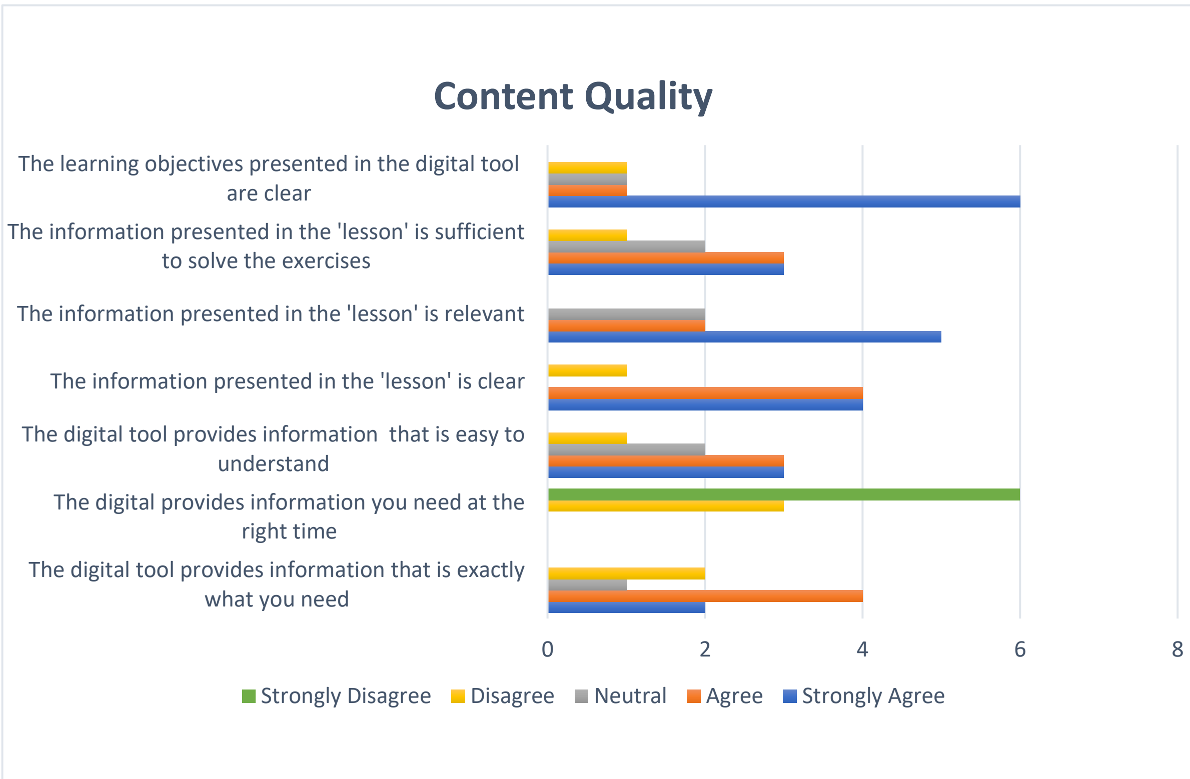


Figure 15 shows the students' perception regarding how personalised their learning path was within the tool. Only 27% of the responses reflected negative views.

The items included in the feedback quality section of the questionnaire intended to assess the quality of the content delivered after exercises were incorrectly answered (e.g., an orange box with steps and cues about how to solve the exercise). Figure 16 shows students' perceptions of the feedback provided. Overall, 84% of the students indicate positive attitudes towards the feedback provided.

Figure 15

Students' Responses Regarding Personalised Learning offered by the DFMT

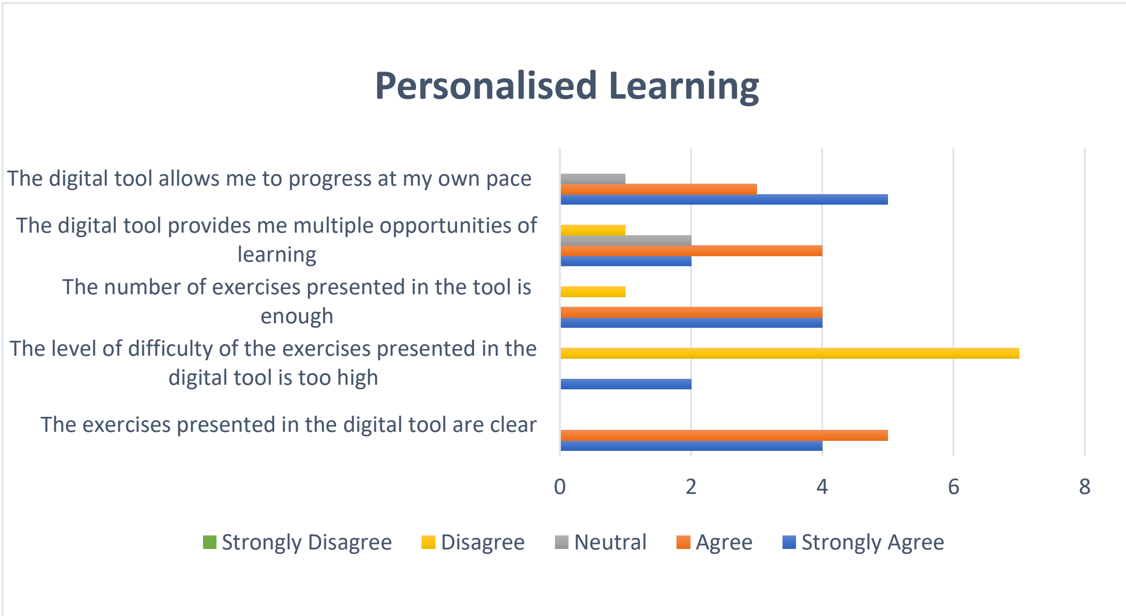
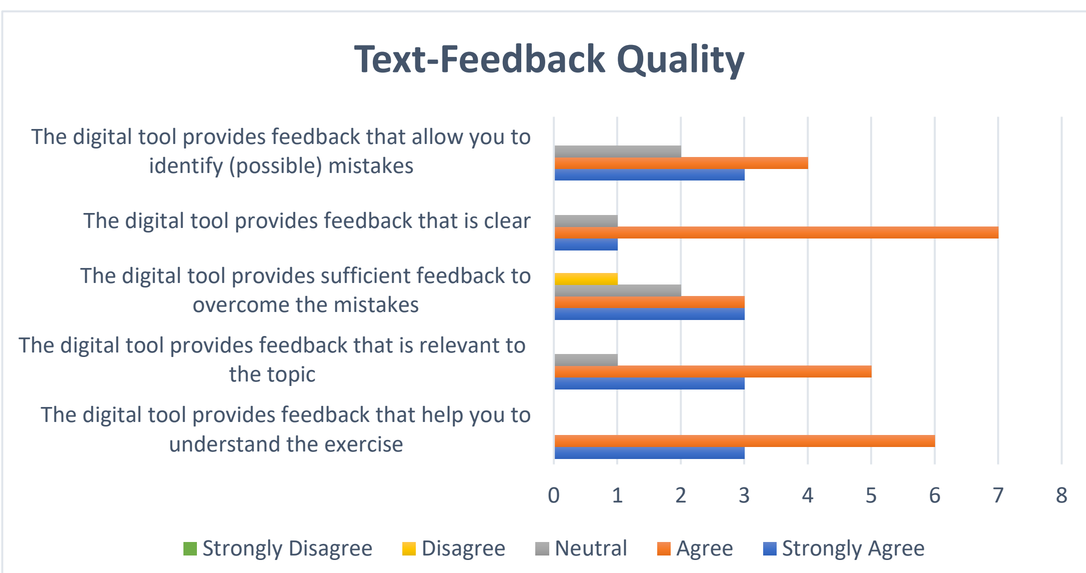


Figure 16

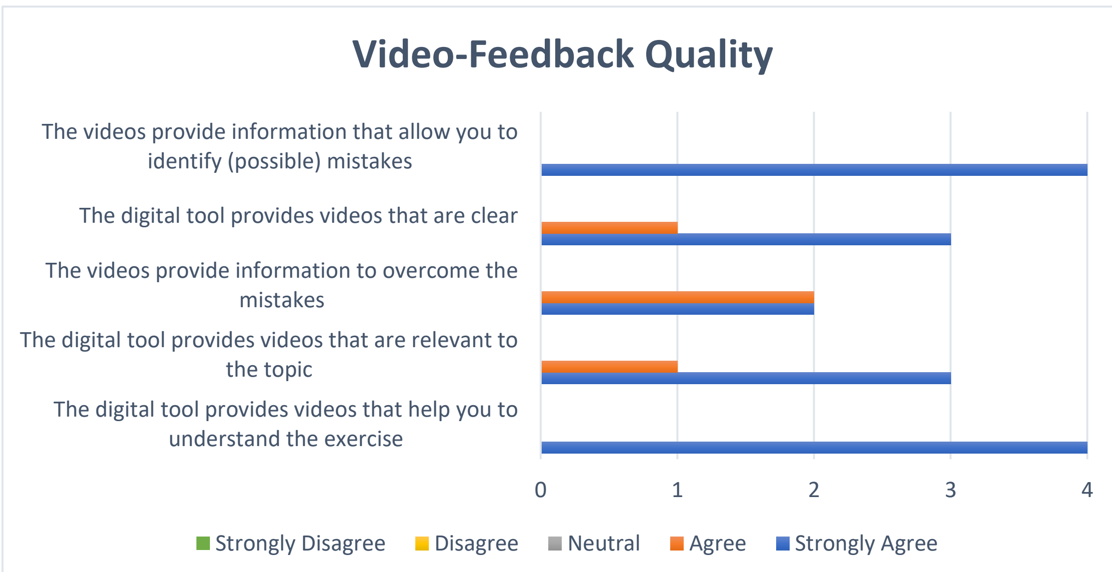
Students' Responses Regarding Text-Feedback included in the DFMT



Regarding the video quality, four of the participants watched one of the videos, in total six videos were watched. Figure 17 contains the responses of the four participants who mostly reported positive opinions regarding the video-feedback quality. Nonetheless, 27% of students stated in the suggestion box that they would like to track their progress, in fact, one of the students wrote: “It would be nice to be able to see your progress and know how much you still have to do”.

Figure 17

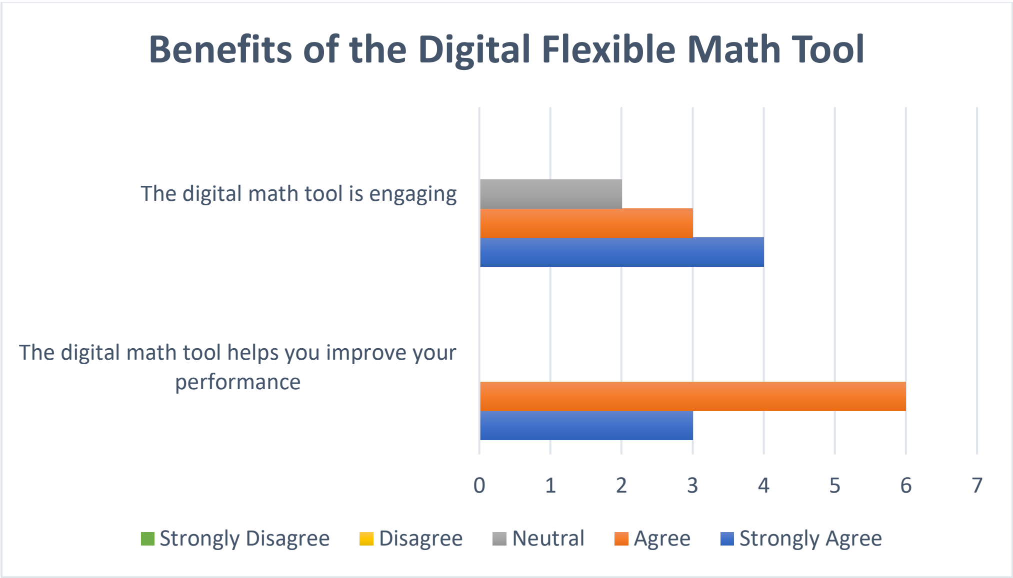
Students' Responses Regarding Video-Feedback included in the DFMT



The last section of the questionnaire included two items that assessed the perception of students towards the benefits of the digital tool, whether they found it engaging and if they believed this tool would help them to improve their math skills. Overall, 89% of the participants reported positive views towards the interaction with the DFMT (see Figure 18). This is in line with some opinions left in the suggestion box such as “getting a right answer after a wrong one motivates me”.

Figure 18

Students' Responses Regarding the Benefits of the DFMT



Second Refinement. After students' responses were revised and analysed, the second refinement of the prototype took place. The first issue addressed is the accessibility of the *lesson* once the exercises are displayed. Unfortunately, this is not possible in Grasple, however, it is decided to add the mathematical definition of each property of exponents rule evaluated in the feedback box. This decision is aligned with the report of Hattie and Timper (2007) who indicate cues are a highly effective form of feedback. The feedback that tracks the students' progress is not possible as the adaptability of the digital tool creates a situation where the number of exercises remaining depends on the students' performance. Therefore, there is not a fixed number of items required to move to the next topic. In short, modifications were made within the operational criteria of Grasple.

5.3.3 Beta Testing: Teacher and Refinement

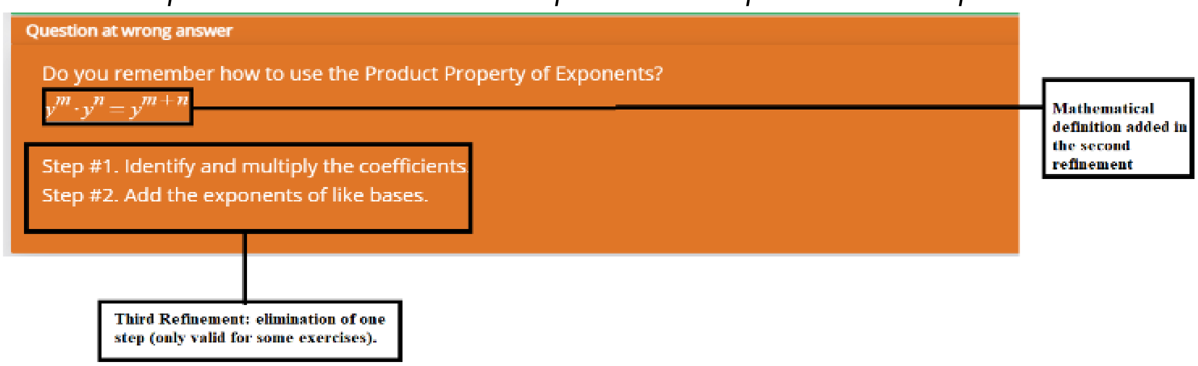
Beta Testing. The goal of conducting the teacher beta testing was to evaluate the functionality of the digital FLP math tool, the alignment of the content with the curriculum and the perception of the teacher towards the digital tool and its possible use in the classroom. Regarding system quality, the teacher commented in the interview: “"I like the layout, it's nice and clear" which suggest the respondent’s positive views toward the tool. In terms of content quality (e, g., *introduction of the subject, lesson* and *exercises*), statements such as “the exercises reflect what we teach them in class” and “the *lesson* contains clear information for students” reflected that the teacher coordinator agreed with the alignment between the information included in the digital tool and the curriculum of the course but also the clarity of the information. In terms of personalised learning, the teacher stated: “The level of exercises I think that's just pretty much what we need” and “what I like about the system is that you have the differentiation in that” which suggested that the items created and its adaptability target students’ needs.

Regarding text-feedback and video-feedback, the teacher coordinator commented: “I think the feedback is sufficient, I think it's pretty much like the feedback that they would get from my teachers’ assistants or from me” and “I think the videos are kind of clear and clean” which indicated positive perception towards the feedback provided. In terms of the benefits of the tool, the following utterances: “the combination of theory and practice would help students to tackle these kinds of problems and to get math skill”, “we are hoping that it saves us a bit of time on one hand time that we can invest in other parts”, and “I think the tool is great, I mean, it's better than what we had and it has some potential, especially with the feedback and with the thing that you could kind of go through the material quicker than with the other one", were examples of the underlined advantages of the digital FLP math tool by the teacher.

Third Refinement. Despite the positive opinions about the use of the DFMT given by the teacher, some utterances suggested the need for the last refinement of the prototype. The first change refers to the feedback provided in the exercises of the Product Property of Exponents. It was discussed with the teacher that step # 2 included was not necessary and it might be confusing for students. Therefore, the number of steps is reduced from three steps (see Figure 12) to two steps (see Figure 19).

Figure 19

Screenshot of the Text-Feedback Provided for One Item After the Third Refinement



The second change made was related to the addition of the video-feedback to the *lesson*. It is important to remark that in the initial design, users only have access to the videos if they incorrectly answer three items. Nevertheless, in the alpha testing, one e-learning specialist suggested given students access to the videos despite their navigation throughout the branching tree. After this was consulted in the second session of the beta testing, the teacher coordinator stated, "I think we get to the point where we have, let's say, different way, different ways of studying, I mean, all depends on how a candidate study, and I know some of them like to learn with videos". As a result, the video-feedbacks were also included in the *lesson* section of the

DFMT. This, give students the opportunity to choose when to access the content and offer them various learning modalities and how to learn the content provided which according to Gordon (2014) support the flexible learning provision.

5. 4 Reflection

Refined Version of the Prototype. After the iterative cycle of testing and refinement, the final version for the prototype of the DFMT is composed of three parts: *introduction to the subject*, *lesson*, and *exercises*. Once the students access the tool, they are presented with the course map as shown in Figure 9. Then, once they click on the *subject* developed (i. e., Property of Exponents), they access the *introduction to the subject* which contains the learning objectives (see Figure 10). Subsequently, users have access to the *lesson* which is constituted by two elements: (1) mathematical definitions of the topic (see Figure 11); (2) videos of each subtopic. Initially, the videos were created to be added in the feedback box, in case of users incorrectly answer three items within a subtopic. However, based on the suggestions made by the teacher coordinator and the e-learning specialist, the video-feedback were also included in the *lesson* regardless of the errors made. Finally, *exercises* are presented to the students. The items were created within flexi-level model which aimed to adapt the level of the item according to the students' performance. First, items about *Product Property* were presented, then *Power Property* and finally, *Quotient Property*. After each item is answered, two types of text-feedback are given. One type is the detailed solution (step-by-step) which is provided in case users correctly answers the item or at the third attempt (i.e., green feedback box). The second type is a question complemented with the mathematical definition of the assessed topic and the sequence of steps that aim to guide students through the problem-solving solution (i. e., orange feedback box). After the recommendations were made by respondents, the information provided in the feedback boxes was reduced to avoid cognitive load (Chu, 2014; Pass et al., 2003). Additionally, embedded videos were included in the orange feedback box in case students incorrectly answers three items within a subtopic.

6. Discussion

The current study investigated the following research question: "***How the development of a Digital Flexible Math Tool with adaptive items and elaborated feedback supports the flexible learning pathways model adopted by the Build-up Course Mathematics offered by the CreaTe Programme at the University of Twente?***". In order to answer it, a four-phase educational design research was conducted. In each phase, a sub-research question was formulated. Below the discussion of each sub-research question is presented.

6. 1 Phase 1: Analysis of Practical Problems

What are the characteristics of Build-up Course Mathematics provided to first-year students of the CreaTe programme at the University of Twente of the University of Twente?

The Creative and Technology programme is considered a STEM programme; therefore, students need a solid math foundation to comprehend advanced math courses and to avoid dropout rates (Koenig & Bao, 2012; Jourdan et al., 2007; P. Edwards & P.M. Edwards, 2003). As a response to the low mathematical literacy of the students at entry-level (OECD, 2021; Lawson 2003), Build-up Course Mathematics was integrated into the curriculum of the CreaTe programme to strengthen incoming students' math basic competencies and prepare them for the advanced math courses. However, teachers are challenged to provide differentiated instruction that fulfils the needs of all students, due to their various academic backgrounds.

Respondents indicated that the diversity of math levels of the students is derived from the adaption of flexible learning pathways measures. For instance, the course is tailored to incoming students with the lowest math literacy, nevertheless, they can decide whether register in the basic course (Build-up Course Mathematics) or the advanced course. Giving students the opportunity to choose between courses reflects the FLP provision adopted by the programme (Gordon, 2014; Ling et al., 2001; Collis, et al., 1997), but leads to a more diverse student body.

A second factor that influences the diversity of students is the elimination of math entry requirements. Although removing math entry requirements facilitates students access to tertiary institutions (Martin & Gonodoga, 2020; Ling et al., 2001), it challenges instructors to address the needs of the heterogeneous student body. To illustrate, in the context of Dutch education, to be accepted to research-oriented higher education institutions such as the University of Twente, students are required to hold a VWO diploma or HBO first-year certificate (Nuffic, 2019). The VWO diploma acquisition implies students took at least one math course (mathematics A, B, C or D), which usually is aligned with their future studies. Particularly, mathematics B and D are designed for students who will attend STEM studies. However, in the context of the CreaTe programme, on average, only 13% of the VWO diploma holders have taken math B and D. This finding is in line with the report of Thomasian (2011) which found that often students do not take challenging math courses in high school.

Another factor that contributes to a diverse student body is internationalization. In the case of the Dutch HEI, the adoption of measures such as the Bologna Declaration led to the increase of international students. In fact, 24% of the incoming student of the CreaTe programme are non-Dutch. Nonetheless, in the baseline of the interviews, respondents stated that they are challenged to identify the students' needs because they are not familiar with non-Dutch educational approaches.

Moreover, van der Wende (2001) assured that the adoption of English as a language of instruction has attracted worldwide students. In the case of the Build-up Course, this is seen by teachers as a drawback because they argue student performance is negatively impacted due to lack of English language skills. This is consistent with the study of Briggs, Dearden and Macaro (2018) who found that some tertiary teachers believe that the lack of English language literacy negatively impacts students' academic performance.

In conclusion, the Build-Up Couse is in the urgency of integrating a digital solution that challenges all students despite their academic background and allow teachers to provide personalised instruction. Furthermore, the unforeseen circumstances experienced in 2020 caused by the novelty of the COVID-19 pandemic challenged all education systems to use digital materials that facilitate students' learning process. As a response to the Coronavirus crisis, educational institutions, particularly the University of Twente integrated ITC educational applications such as Grasple to facilitate the transition from in-person education to completely online education (Halman & Huisman, 2021).

6. 2 Phase 2: Design and Development of a Solution

How to develop a digital tool that addresses the needs of the students and teachers of the Build-up Course Mathematics?

In phase one of this study was found that the Build-up Course Mathematics has adopted FLP measures to facilitate access to diverse students. Also, it was found that the integration of a digital solution that support teachers to provide personalised learning and allow students to take control of their learning process was needed. The integration of technology in learning environments is essential not only to support FLP (Gordon, 2014) but also personalised learning (Huang & Shiu, 2012; Yarandi et al., 2012; Paramythis & Loidl-Reisinger, 2003; Sampson & Karagiannidis, 2002). Therefore, the design and development of the Digital Flexible Math Tool are derived from an iterative cycle between the design propositions and the designed requirements described in section 5.2 (McKenney & Reeves, 2019).

The prototype of the DFMT is constructed under the operational criteria of Grasple (see section 5.2.2). The use of Grasple is aligned with the FLP measures since permit students to access the content at any time, place and pace (Gordon, 2014; Ling et al., 2001). Two essential components were included in the prototype aiming to challenge students at their own level but also boost their math knowledge and skills that permit them to satisfactorily complete the advanced math courses of the programme. The first component is related to the use of flexi-level items. That means, following the initial item of level n, students are asked harder or easier items based on their initial answer. Gordon (2014) assures that the use of flexible-level items can be considered as FLP provision but also as personalized learning since the content is adapted to the students' needs. Additionally, flexi-level items provide a more accurate measurement of students' abilities, reduce random guessing and yield scores of higher reliability (Betz & Weiss, 1975; Weiss & Betz, 1973).

The other component included in the digital solution refers to feedback. Information permitting students and teachers to monitor their progress is considered part of the operational criteria of Grasple. However, elaborated feedback (e. g., step by step) is included in the prototype to allow students to move forward in their learning process. This decision is consistent with various studies (Hattie & Timper, 2007; Sweller, van Merrienboer, & Paas, 1998) which indicate that the use of steps-by-steps as feedback enables learners to construct and transfer knowledge using inductive thinking. Besides the text-feedback provided after items are answered, video-feedback is provided in case users have consecutively answered three items wrong. The use of video-feedback is in line with the study of Mayer (2014) who indicated that the use of words combined with images have better results when it comes to processing information, but also with Morton and Qu (2015) who affirmed that video-feedback improve students' outcomes.

6. 3 Phase 3: Iterative Cycles of Testing and Refinement

What are the perceptions of students and teachers of the Digital Flexible Math Tool developed for the Build-up Course Mathematics?

The evaluation process conducted in the current study aimed to examine the perceptions of the teacher coordinator and students towards the DFMT. However, before the beta testing, the alpha testing was conducted with e-learning specialists intending to evaluate the design solution included in the prototype and its functionality. McKenney and Reeves (2019) affirmed that alpha testing plays an important role in educational design research evaluation process since it assesses the design ideas integrated into the prototype and its alignment with the design propositions and design requirements.

Respondents of the alpha testing expressed high levels of satisfaction about the design ideas included in the prototype. Nevertheless, based on their opinions, the information provided in the feedback orange box was reduced to avoid students' cognitive overload and enhance their problem-solving skills (Pass et al., 2003; Sweller et al., 1998).

In the first session of the beta testing, students reported positive attitudes towards the DFMT. In fact, 72% of the overall opinions reflected their positive views. Having positive attitudes not only facilitate the integration of technology in learning environments (Kisanjara, 2014), but also increase students' performance (Eyyam & Yaratan, 2014). Nevertheless, 36% of the respondents suggested having access to the *lesson* while the exercises are presented. Due to the operational criteria of Grasple, this modification was not possible, however, the mathematical definition of the topic assessed was included in the orange box of the feedback provided (as shown in Figure 21). According to Hattie and Timper (2007), the use of cues in feedback is highly effective. Additionally, 27% of the participants indicated that they would like to be able to track their progress while they are navigating in the branching tree. Nonetheless, the adaptive nature of the branching tree is not possible.

Regarding the second session of the beta testing, the qualitative data showed that in general, the teacher coordinator was satisfied with the DFMT functionality and its alignment with the curriculum of the course. Teacher's positive opinions is a determinant factor that facilitates changes related to technology integration in the classroom (Inan & Lowther, 2010; Baylor & Ritchie, 2002). However, the videos, initially designed for feedback, were included in the *lesson* of the DMFT as suggested by the respondent. This was done with the purpose of adding flexibility to the tool and offering students diverse learning modalities (Martin & Godonoga, 2020; Gordon, 2014; Ling et al., 2001; Collis, et al., 1997).

6. 4 Phase 4: Reflection

Which characteristics of the Digital Flexible Math Tool can be improved to facilitate its possible integration into the Build-up Course Mathematics?

The final version of the prototype of the DFMT resulted after three iterative cycles of testing and refinement were conducted. It contains different types of learning modalities such as video and text which aim to support the flexibility of the tool (Ling et al., 2001; Collis, et al., 1997). Also, the DFMT uses a flexi-level branching tree model which displays items that aim to adapt the content to the academic needs of the students (Gordon, 2014; Weiss & Betz, 1973). Finally, the digital tool developed includes elaborative feedback that directs and facilitates the learning process, but also improve students' performance (Hattie & Timperley, 2007; Shute, 2007; Moreno, 2004; Black & Wiliam,1998; Pridemore & Klein, 1995). In fact, the feedback delivered varies according to the students' answer.

In the evaluation phase, it was found that the respondents had positive perceptions of the DFMT. However, there are some elements, that according to the respondents, can improve users experience of the digital tool. Firstly, students on the beta testing reported the need to access the *lesson* once the *exercises* are displayed. Due to the operational criteria of Grasple, this is not possible. For that reason, the mathematical definition of the topic assessed was included in the orange feedback box (see section 5.3.2). However, it would be beneficial to include a bottom that allows students to access the *lesson* because the information included in the orange feedback box is displayed only after the first incorrect attempt, which might have a negative impact on students' motivation (Afzal, Ali, Aslam Khan, & Hamid, 2010).

The second recommendation is related to the video-feedback. Although participants of beta testing indicated satisfactory views regarding the videos, only a few students watched at least one video. Since the last refinement of the prototype, the videos were added to the *lesson*, it is recommended to investigate the effectiveness of the videos at a deeper level.

Finally, the third recommendation refers to the information provided to teachers about the progress of the students. After the first session of the beta testing, it was found that the information provided by the Grasple Logs was very limited. For instance, in the teacher profile, it was only possible to visualize the performance of the students who finished the three branching trees. That is if the students did not complete the subject and exit from the DFMT, the student information is not stored on the teacher *monitor panel*. For this reason, it is recommended to ask the Grasple team to modify this operational criterion, so teachers are provided with more accurate information about the progress of the students.

6. 5 Limitations and Future Research

Few limitations were encountered in the current study. The first limitation was related to the nature of the participants of the first session of beta testing. McKenney & Reeves (2019) affirmed that evaluating the prototype in the local culture is necessary to determine the effectiveness and impact of the prototype in the intended setting. For that reason, it was initially intended to evaluate the prototype with the students of the CreaTe programme registered in the Build-up Course Mathematics. However, none of the students reached, participated in the study. This might have implications on the viability of the intended implantation of the DFMT. Additionally, the sample size was significantly small which does not necessarily reflect an accurate view of the students' perception towards the digital tool.

The second limitation referred to the reliability of each factor included in the questionnaire. The questionnaire used in this study was adapted from the e-learning systems success (ELSS) developed by Y. S. Wang et al. (2007). Although the original instrument reposted high reliability, the factor analysis of the new dimension included in the questionnaire of this study (e.g., personalised learning, text-feedback quality and video-feedback quality) were not evaluated.

Lastly, the time employed to conduct the research was limited. Therefore, the effectiveness and impact of the DFMT were not investigated. McKenney and Reeves (2019) proposed three clusters of prototype testing to effectively integrate solutions in educational research: assessment of design ideas; evaluation of prototype functionality and alignment with the context and effect; and impact of the prototype in the desired setting. The current study only investigated the first two clusters. For that reason, to ensure effective integration of the DFMT in the Build-up Course Mathematics it is recommended to examine the impact of the digital tool on the first-year students registered in the course.

Further research should consider the potential effects of the flexi-level branching tree developed in this study on students' performance. Particularly, the extent to which the use of flexi-level items supports personalised learning. For example, if the number of levels (e.g., $n - 2$ to $n + 3$) included in the current study fulfils the needs of the first-year students of the CreaTe programme. Additionally, further research on the impact of video-feedback and text-feedback might extend the explanations of elaborated feedback. Particularly, if the information included in the feedback is sufficient to help students to improve their performance.

6. 6 Conclusion

The main goal of this study was to investigate: *How the development of a Digital Flexible Math Tool with adaptive items and elaborated feedback supports the flexible learning pathways model adopted by the Build-up Course Mathematics offered by the CreaTe Programme at the University of Twente?* It was found that the Build-up Course Mathematics and the Creative and Technology Programme have been adopting flexible measures such as elimination of entry requirements, English as a language of instruction, modular structure (Martin & Godonoga,2020;

Gordon, 2014, Ling et al., 2001) which aim to facilitate the access of students to the higher education system. However, teachers are challenged to provide instruction that fulfils the needs of a heterogenous student body. In the context of Build-up Course Mathematics, teachers are not only challenged to provide instruction to the wider spectrum of math abilities of the incoming students but also the lack of math literacy (Jourdan, Cretchley, & Passmore, 2007; Lawson, 2003).

Therefore, a Digital Flexible Math Tool was developed to support the learning process of the students. The DFMT aims to support the flexible learning pathways model adopted by the CreaTe programme since it allows students to access the content at any time, place, and learning modalities such as video and text (Gordon, 2014, Ling et al., 2001). Additionally, the flexi-level adaptive items included in the tool intended to provide personalised learning addressing the individual needs of the students and allowing them to progress at their own pace (UNESCO, 2012; U.S. Department of Education, 2010). Moreover, the provision of elaborated feedback aims to increase student knowledge, skills and understanding of the content (Hattie & Timperley, 2007; Black & Wiliam, 1998).

In general, teachers, students and e-learning specialists had positive views regarding the DFMT in terms of functionality, content (i.e., learning objectives, mathematical definition, exercises and feedback) accuracy and alignment with the context. Some of the suggestions made by the respondents of the evaluation phase were included in the refinement of the prototype. The modifications aim to provide effective text-feedback reducing the cognitive load (Pass et al., 2003; Sweller et al., 1998) and providing information that intends to eliminate the gap between their current level of performance and the desired level of performance of the students (Hattie & Timperley, 2007; Black & Wiliam, 1998). Additionally, to increase the flexibility of the tool, students will have access to the video-feedback in the *lesson* or in case they incorrectly answer three items of a subtopic (Ling et al., 2001).

Further research is needed to investigate the effectiveness and impact of the DFMT on first-year students registered in the Build-up Course Mathematics of the CreaTe bachelor programme.

7. List of References

Allen, I. E., & Seaman, J. (2010). Class Differences: Online Education in the United States. *Sloan Consortium.* ERIC. https://files.eric.ed.gov/fulltext/ED529952.pdf.

Alonso-Díaz, L., Blázquez-Entonado, F. (2009). Are the Functions of Teachers in e-Learning and Face-to-Face Learning Environments Really Different? Educational Technology & Society, 12 (4), 331–343. https://www.jstor.org/stable/pdf/jeductechsoci.12.4.331.pdf

Asarta, C. J., & Schmidt, J. R. (2020). The effects of online and blended experience on outcomes in a blended learning environment. *The Internet and Higher Education*, *44*, 100708. https://doi.org/10.1016/j.iheduc.2019.100708

Aspin, D., & Chapman, J. (2001). Towards a philosophy of lifelong learning. In *International handbook of lifelong learning* (pp. 3-33). Springer, Dordrecht.

Akkoyunlu, B., & Yilmaz-Soylu, M. (2008). A study of student's perceptions in a blended learning environment based on different learning styles. *Journal of Educational Technology & Society*, *11*(1), 183-193.

Afzal, H., Ali, I., Aslam Khan, M., & Hamid, K. (2010). A study of university students' motivation and its relationship with their academic performance. *Available at SSRN 2899435*.

Baylor, A. L., & Ritchie, D. (2002). What factors facilitate teacher skill, teacher morale, and perceived student learning in technology-using classrooms?. *Computers & education*, *39*(4), 395-414. https://doi.org/10.1016/S0360-1315(02)00075-1

Bell, T., Cockburn, A., McKenzie, B., & Vargo, J. (2001). Digital Lectures: If You Make Them, Will Students Use Them? Constraints on Effective Delivery of Flexible Learning Systems. *Interactive Multimedia Journal of Computer-Enhanced Learning, 3*(2). http://imej.wfu.edu/articles/2001/2/06/index.asp

Betz, N. E., & Weiss, D. J. (1975). *Empirical and Simulation Studies of Flexilevel Ability Testing. Research Report No. 75-3* (ED111861). ERIC. https://eric.ed.gov/?id=ED111861

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative research journal*, *9*(2), 27. Doi: 10.3316/QRJ0902027

Briggs, J. G., Dearden, J., & Macaro, E. (2018). English medium instruction: Comparing teacher beliefs in secondary and tertiary education. *Studies in Second Language Learning and Teaching*, *8*(3), 673-696. http://dx.doi.org/10.14746/ssllt.2018.8.3.7

Caswell, T., Henson, S., Jensen, M., & Wiley, D. (2008). Open Educational Resources: Enabling universal education. *International Review of Research in Open and Distance Learning, 9*(1).

Clark, R. C., Mayer, R. E. (2003). *E-Learning and the Science of Instruction*. Pfeiffer.

Chen, D. T. (2003). Uncovering the provisos behind flexible learning. *Journal of Educational Technology & Society*, *6*(2), 25-30. https://www.jstor.org/stable/jeductechsoci.6.2.25?seq=1

Chen, Y., Johri, A., & Rangwala, H. (2018). Running out of stem: a comparative study across stem majors of college students at-risk of dropping out early. In *Proceedings of the 8th international conference on learning analytics and knowledge* (pp. 270-279).

Chu, H.-C. (2014). Potential Negative Effects of Mobile Learning on Students' Learning Achievement and Cognitive Load—A Format Assessment Perspective. Educational Technology & Society, 17 (1), 332–344. https://www.jstor.org/stable/pdf/jeductechsoci.17.1.332.pdf

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7th ed.). London: Routledge.

Collis, B., Moonen, J., & Vingerhoets, J. (1997). Flexibility as a key construct in European training: Experiences from the TeleScopia Project. *British journal of educational technology, 28*(3), 199-217. https://doi.org/10.1111/1467-8535.00026

Chamberlin, M., & Powers, R. (2010). The promise of differentiated instruction for enhancing the mathematical understandings of college students. *Teaching Mathematics and Its Applications: An International Journal of the IMA, 29*(3), 113-139. https://doi.org/10.1093/teamat/hrq006

D'Antoni, S. (2009). Open educational resources: Reviewing initiatives and issues. *Open Learning: The Journal of Open, Distance and e-Learning, 24*(1), 3-10, DOI: 10.1080/02680510802625443

Dempsey, J. V., Driscoll, M. P., & Swindell, L. K. (1993). Text-based feedback. *Interactive instruction and feedback*, 21-54.

Dempsey, J. V., & Wager, S. U. (1988). A taxonomy for the timing of feedback in computer-based instruction. *Educational Technology, 28*(10), 20-25. https://www.jstor.org/stable/44427652

Donkin, R., Askew, E., & Stevenson, H. (2019). Video feedback and e-Learning enhances laboratory skills and engagement in medical laboratory science students. *BMC medical education*, *19*(1), 1-12. https://doi.org/10.1186/s12909-019-1745-1

Dorce, C. (2020) History of Mathematics as an integration and social cohesion tool in the classroom. *International Journal of Mathematical Education in Science and Technology.* doi: 10.1080/0020739X.2020.1827171

Duarte, R., de Oliveira-Pires, A. L., & Nobre, Â. L. (2018). Mature learners' participation in higher education and flexible learning pathways: lessons learned from an exploratory experimental research. In *Contributions to Higher Engineering Education* (pp. 33-53). Springer, Singapore. http://dx.doi.org/10.1109/CISPEE.2016.7777731

Edwards, P., & Edwards, P. M. (2003). Tackling the mathematics problem with MathinSite. *Global Journal of Engineering Education, 7*(1). http://www.wiete.com.au/journals/GJEE/Publish/vol7no1/EdwardsEdwards.pdf

European Commission. 2015. *Dropout and completion in higher education in Europe*. Main Report. Luxembourg: Publications Office of the European Union.

Eyyam, R., & Yaratan, H. S. (2014). Impact of use of technology in mathematics lessons on student achievement and attitudes. *Social Behavior and Personality: an international journal*, *42*(1), 31S-42S. https://doi.org/10.2224/sbp.2014.42.0.S31

Faulkner, F., Hannigan, A., & Gill, O. (2010). Trends in the mathematical competency of university entrants in Ireland by leaving certificate mathematics grade. *Teaching Mathematics and Its Applications: An International Journal of the IMA*, *29*(2), 76-93.

Fyfe, E. R. (2016). Providing feedback on computer-based algebra homework in middle-school classrooms. *Computers in Human Behavior*, *63*, 568-574. https://doi.org/10.1016/j.chb.2016.05.082

Fukkink, R. G., Trienekens, N., & Kramer, L. J. (2011). Video feedback in education and training: Putting learning in the picture. *Educational Psychology Review*, *23*(1), 45-63. DOI 10.1007/s10648-010-9144-5

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *Internet and Higher Education*, 7, 95–105. https://doi.org/10.1016/j.iheduc.2004.02.001.

Gecer, A., & Dag, F. (2012). A blended learning experience. *Educational Sciences: Theory and Practice*, *12*(1), 438-442.

Graham, C. R. (2006). Blended learning systems: Definition, current trends and future directions. In C. J. Bonk & C. R. Graham (Eds.), The handbook of blended learning: Global perspectives, local designs (pp. 3–21). San Francisco: Pfeiffer

Gillebaart, T., & Bellinga, P. (2018). From co-created learning resources to personalised online courses for blended learning. In *Looking Back, Looking Forward. Proceedings of the 10th International Conference on Teaching Statistics (ICOTS10 2018), Kyoto, Japan.*

Gordon, N. (2014). Flexible pedagogies: Technology-enhanced learning. *The Higher Education Academy*, 1-24. https://www.hv.se/globalassets/dokument/stodja/paper-theme-3.pdf

Inan, F. A., & Lowther, D. L. (2010). Factors affecting technology integration in K-12 classrooms: A path model. *Educational technology research and development*, *58*(2), 137-154. https://doi.org/10.1007/s11423-009-9132-y

Halman, J. I. M., & Huisman, H. M. (2021). The evaluation of Covid-19 crisis management at the University of Twente: The first phase of the covid-19 crisis. https://doi.org/10.3990/1.9789036551595

Hameed, S., Badii, A., & Cullen, A. J. (2008, May). Effective e-learning integration with traditional learning in a blended learning environment. In *European and Mediterranean Conference on Information Systems* (pp. 25-26).

Hartsell, T., Herron, S. S., Fang, H., & Rathod, A. (2010). Improving teachers' self-confidence in learning technology skills and math education through professional development. *International Journal of Information and Communication Technology Education (IJICTE)*, *6*(2), 47-61.

Higgins, K., Huscroft-D'Angelo, J., & Crawford, L. (2019). Effects of technology in mathematics on achievement, motivation, and attitude: A meta-analysis. *Journal of Educational Computing Research*, *57*(2), 283-319. doi: 10.1177/0735633117748416

Higgins, A., & Northover, M. (2011). Implementing an online system: Voices of experience. *Flexible pedagogy, flexible practice: Notes from the trenches of distance education*, 127-138. In: Burge, Elizabeth; Campbell Gibson, Chère and Gibson, Terry eds. Flexible Pedagogy, Flexible Practice: Notes from the Trenches of Distance Education. Issues in Distance Education. Edmonton, AB: Athabasca University Press, pp. 139–147. http://www.aupress.ca/index.php/books/120203

Horst C., Kubbe L., van de Rotten B., Peters K., Bouwer A., Bredeweg B. (2020) Exploring the Design and Impact of Online Exercises for Teacher Training About Dynamic Models in Mathematics. In: Alario-Hoyos C., Rodríguez-Triana M., Scheffel M., Arnedillo-Sánchez I., Dennerlein S. (eds) Addressing Global Challenges and Quality Education. EC-TEL 2020. Lecture Notes in Computer Science, vol 12315. Springer, Cham. https://doi-org.ezproxy2.utwente.nl/10.1007/978-3-030-57717-9_34

Huang, F. (2006). Internationalization of curricula in higher education institutions in comparative perspectives: Case studies of China, Japan and the Netherlands. *Higher Education*, *51*(4), 521-539. https://doi.org/10.1007/s10734-004-2015-6

Huang, S. L., & Shiu, J. H. (2012). A user-centric adaptive learning system for e-learning 2.0. *Journal of Educational Technology & Society*, *15*(3), 214-225. https://www.jstor.org/stable/10.2307/jeductechsoci.15.3.214

Hylén, J. (2006). Open educational resources: Opportunities and challenges. *Proceedings of open education*, *4963*. www.oecd.org/edu/ceri

Jourdan, N., Cretchley, P., & Passmore, T. (2007). Secondary-tertiary transition: what mathematics skills can and should we expect this decade? In: Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australasia (MERGA 30) (Vol. 2, pp. 463-472). Mathematics Education Research Group of Australasia (MERGA). https://eprints.usq.edu.au/3761/2/Jourdan_Cretchley_Passmore_Merga_07_Pubrversion.pdf

Joyce, A. (2006). *OECD study of OER: Forum report*. *Internet discussion forum. Open educational resources findings from an OECD study.* OECD Center for Educational Research and Innovation. https://www.researchgate.net/profile/Alexa-Joyce/publication/265183257_OECD_study_of_OER_forum_report/links/564b064e08ae9cd9c827cf5a/OECD-study-of-OER-forum-report.pdf

Karagiannidis, C., & Sampson, D. (n.d.) The KOD" Knowledge on Demand" Project: A Step Towards Personalised Learning.

Kerr, P. (2016). Adaptive learning. *Elt Journal*, *70*(1), 88-93.

Kisanjara, S. B. (2014). Students' attitudes and readiness assessment towards e-learning in higher learning institutions. *International Journal of Engineering Research & Technology (IJERT)*, *3*(1), 3155-3166. https://www.ijert.org/

Koenig, K., Schen, M., Edwards, M., & Bao, L. (2012). Addressing STEM Retention Through a Scientific Thought and Methods Course. *Journal of College Science Teaching*, *41*(4). https://www.researchgate.net/publication/292720004

Kramarski, B., & Gutman, M. (2006). How can self-regulated learning be supported in mathematical E-learning environments?. *Journal of Computer Assisted Learning*, *22*(1), 24-33. https://doi.org/10.1111/j.1365-2729.2006.00157.x

Krause, U. M., Stark, R., & Mandl, H. (2009). The effects of cooperative learning and feedback on e-learning in statistics. *Learning and instruction*, *19*(2), 158-170. https://doi.org/10.1016/j.learninstruc.2008.03.003

Lane, A., (2011). Adding flexibility to higher education using OERs: lessons from the Open University. In: Burge, E. & Campbell G. (Eds). *Flexible Pedagogy, Flexible Practice: Notes from the Trenches of Distance Education*. Issues in Distance Education. Edmonton, AB: Athabasca University Press, pp. 139–147. http://www.aupress.ca/index.php/books/120203

Lawson, D. (2003). Changes in student entry competencies 1991–2001. *Teaching mathematics and its applications*, *22*(4), 171-175.

Lin, J., Ho, C., Sadiq, W., & Orlowska, M. E. (2002). Using workflow technology to manage flexible e-learning services. *Educational Technology & Society*, *5*(4), 116-123. https://www.jstor.org/stable/10.2307/jeductechsoci.5.4.116

Ling, P., Arger, G., Smallwood, H., Toomey, R., Kirkpatrick, D., & Barnard, I. (2001). The effectiveness of models of flexible provision of higher education. *Department of Education, Training and Youth Affairs, Commonwealth of Australia*.

Martin, M., & Godonoga, A. (2020). SDG 4: policies for flexible learning pathways in higher education: taking stock of good practices internationally.

Mayer, R. E., (2014). *The Cambridge handbook of multimedia learning* (2nd ed.). Cambridge University Press. https://doi-org.ezproxy2.utwente.nl/10.1017/CBO9781139547369

Mbugua, Z. K., & Muthomi, M. W. (2014). Effectiveness of differentiated instruction on secondary school students' achievement in mathematics. *International Journal of Applied Science and Technology*, *4*(1), 116-122.

McKenney, S., & Reeves, T. C. (2019). *Conducting educational design research* (2nd ed.). Abingdon, OX: Routledge.

Miao, F., Mishra, S., & McGreal, R. (2016). *Open educational resources: policy, costs, transformation*. UNESCO and Commonwealth of Learning Publishing. last part document .docx

Miller, A., & ONeill, O. (2014). Supporting successful learning pathways using e-portfolios and mobile devices. http://www.avetra.org.au/data/Conference_2011_pres./95._Allison_Miller_Owen_ONeill_paper.pdf

Ministry of Education, Culture and Science. (2015). The value of knowledge. Strategic agenda for higher education and research 2015-2025. Retrieved from https://www.government.nl/documents/reports/2015/07/01/the-value-of-knowledge

Moitus, S., Weimer, L., & Välimaa, J. (2020). Flexible learning pathways in higher education: Finland's country case study for the IIEP-UNESCO SDG4 project in 2018–2021. Julkaisut/Kansallinen koulutuksen arviointikeskus.

Moreno, R. (2004). Decreasing cognitive load for novice students: Effects of explanatory versus corrective feedback in discovery-based multimedia. *Instructional science*, *32*(1), 99-113. https://doi.org/10.1023/B:TRUC.0000021811.66966.1d

Morton, K., & Qu, Y. (2015, July). A feedback effectiveness oriented math word problem E-Tutor for E-Learning environment. In *2015 IEEE 15th International Conference on Advanced Learning Technologies* (pp. 301-302). IEEE. doi: 10.1109/ICALT.2015.40

Murphy, A. (2013). Open educational practices in higher education: Institutional adoption and challenges. *Distance Education*, *34*(2), 201-217. https://doi.org/10.1080/01587919.2013.793641

Nevalainen, M. K., Mantyranta, T., & Pitkala, K. H. (2010). Facing uncertainty as a medical student—a qualitative study of their reflective learning diaries and writings on specific themes during the first clinical year. *Patient education and counseling*, *78*(2), 218-223. https://doi.org/10.1016/j.pec.2009.07.011

Nuffic: The Dutch Organization for Internationalisation in Education. (2019). *The education of the Netherlands*. https://www.nuffic.nl/sites/default/files/2020-08/education-system-the-netherlands%20%281%29.pdf

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist*, *38*(1), 1-4. doi: 10.1207/S15326985EP3801_1

Paramythis, A., & Loidl-Reisinger, S. (2003). Adaptive learning environments and e-learning standards. [Conference presentation]. *Second European Conference on e-learning 1*(2003), 369-379.

Phillippi, J., & Lauderdale, J. (2018). A guide to field notes for qualitative research: Context and conversation. *Qualitative health research*, *28*(3), 381-388. https://doi.org/10.1177/1049732317697102

Poon, J. (2013). Blended learning: An institutional approach for enhancing students' learning experiences. *Journal of online learning and teaching*, *9*(2), 271-288.

Pridemore, D. R., & Klein, J. D. (1995). Control of practice and level of feedback in computer-based instruction. *Contemporary Educational Psychology*, *20*(4), 444-450. https://doi.org/10.1006/ceps.1995.1030

OECD (2021). Mathematics performance (PISA) (indicator). doi: 10.1787/04711c74-en (Accessed on 22 January 2021). https://data.oecd.org/pisa/mathematics-performance-pisa.htm

OECD (2021). PISA 2021: Mathematics framework. https://pisa2021-maths.oecd.org/

Ostrow, K., & Heffernan, N. (2014). Testing the multimedia principle in the real world: a comparison of video vs. Text feedback in authentic middle school math assignments. In *Educational Data Mining 2014*.

Reeves, T. C. (2006). Design research from a technology perspective. In J. van den Akker, K. Gravemeijer, S. McKenney & N. Nieveen (Eds.), Educational design research (pp. 52-66). London: Routledge.

Rijken, S., Maas, I., & Ganzeboom, H. B. (2007). The Netherlands: Access to higher education-institutional arrangements and inequality of opportunity. *Stratification in higher education. A comparative study*, 266-293.

Rubin, A. (1999). Technology Meets Math Education: Envisioning a Practical Future Forum on the Future of Technology in Education.

Saul, C., Runardotter, M., & Wuttke, H. D. (2010, October 24-27). *Towards feedback personalisation in adaptive assessment* [Conference Paper]. EDEN Research Workshop. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1005284&dswid=9634

Sampson, D., & Karagiannidis, C. (2002). Personalised learning: educational, technological and standarisation perspective. *Digital Education Review*, (4), 24-39. http://www.ub.es/multimedia/iem

Setyaningrum, W. (2018). Blended Learning: Does it help students in understanding mathematical concepts?. *Jurnal Riset Pendidikan Matematika*, *5*(2), 244-253.

Schlöglmann, W. (2006). Lifelong Mathematics Learning--A Threat or an Opportunity? Some Remarks on Affective Conditions in Mathematics Courses. Adults Learning Mathematics, 2(1), 6-17. https://files.eric.ed.gov/fulltext/EJ1055354.pdf

Smyth, S., Houghton, C., Cooney, A., & Casey, D. (2012). Students' experiences of blended learning across a range of postgraduate programmes. *Nurse education today*, *32*(4), 464-468. https://doi.org/10.1016/j.nedt.2011.05.014

Steen, L. A. (1987). Mathematics education: A predictor of scientific competitiveness. *Science*, *237*(4812), 251-302. https://www.jstor.org/stable/1699967

Sweller, J., van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational psychology review*, *10*(3), 251-296. doi: 10.1023/A:1022193728205

The World Bank Data Catalog. (2020). School enrollment, tertiary (%gross)-Netherlands. https://data.worldbank.org/indicator/SE.TER.ENRR?end=2018&locations=NL&start=1971&view=chart.

UNESCO. (2012). *Personalised learning: a new ICT-enabled education approach*. [Policy Brief]. Institute for Information Technologies in Education http://iite.unesco.org/pics/publicationsen/files/3214716.pdf

UNESCO. (2018). Flexible learning pathways in higher education. http://www.iiep.unesco.org/en/our-expertise/flexible-learning-pathways-higher-education

U.S. Department of Education, Office of Educational Technology. (2010). *Transforming American Education: Learning Powered by Technology.* Education Publications Center. http://www.ed.gov/about/offices/list/opepd/ ppss/reports.html.

van den Hurk, A., Meelissen, M., & van Langen, A. (2019). Interventions in education to prevent STEM pipeline leakage. *International Journal of Science Education*, *41*(2), 150-164. https://doi.org/10.1080/09500693.2018.1540897

van der Wende, M. C. (2001). Internationalisation policies: about new trends and contrasting paradigms. *Higher education policy*, *14*(3), 249-259.

VSNU: Association of Dutch Universities. (2021). *Intake Bachelor's and Master's Students.* https://www.vsnu.nl/nl_NL/feiten-en-cijfers.html

Wang, Z., Gong, S. Y., Xu, S., & Hu, X. E. (2019). Elaborated feedback and learning: Examining cognitive and motivational influences. *Computers & Education*, *136*, 130-140. https://doi.org/10.1016/j.compedu.2019.04.003

Wang, Y. S., Wang, H. Y., & Shee, D. Y. (2007). Measuring e-learning systems success in an organizational context: Scale development and validation. *Computers in Human Behavior*, *23*(4), 1792-1808. https://doi.org/10.2190/YWPN-H3DP-15LQ-QNK8

Weiss, D. J., & Betz, N. E. (1973). Ability Measurement: Conventional or Adaptive? (ED104930). ERIC. https://eric.ed.gov/?id=ED104930

Winter, R. (2002). Flexible learning. *Australian Educational Computing*, *17*(2), 26-30. http://acce.edu.au/sites/acce.edu.au/files/pj/journal/AEC_vol17_2_2002%20Flexible%20Learning.pdf

Yarandi, M., Jahankhani, H., & Tawil, A. R. H. (2012, September). An adaptive e-learning Decision support system. In 2012 15th International Conference on Interactive Collaborative Learning (ICL) (pp. 1-5). IEEE. DOI: 10.1109/ICL.2012.6402141

Yen, J. C., & Lee, C. Y. (2011). Exploring problem solving patterns and their impact on learning achievement in a blended learning environment. *Computers & Education*, *56*(1), 138-145. https://doi.org/10.1016/j.compedu.2010.08.012

8. Appendices

8. 1 Appendix A: Interview Scheme

The scheme of the semi-structured interview conducted in the Phase 1: Analysis of Practical Problems is presented as follow.

Problem identification. The questions made in this section aim to ask about the current, desired situation of the CreaTe Programme and the possible causes of discrepancy.

- Coud you please explain the role in the CreaTe programme/Build-up Course Mathematics?
- What are the characteristics of the CreaTe programme/Build-up Course Mathematics?
- What are the expected outcomes?
- Could you please explain why the understanding of mathematics plays an important role in this context?
- What is the average performance of the students in mathematics courses?

Context identification. The questions made in this section aim to find out about the organizational context, resources available, pedagogy and curriculum.

- What is the methodology of the class? Teacher-centred/student-centred/ are the lectures in the traditional environment?
- Could you please talk about the structure of the course in terms of what activities take place, and what is the daily structured, the assessments?
- How teachers and teacher assistants address the different levels of the students?
- How is the feedback provided?
- What happens if the students do not meet the minimum requirements to pass the course?
- Is the material used in the class taken from a textbook or website or they are created by teachers/teacher assistants?
- Is the course mandatory?
- Is there any flexibility among the two levels?
- What is the next math course that the students will take?

Characteristics of the Stakeholders. The questions made in this portion of the interview aimed to get the characteristic of the teacher, teachers' assistants, and students

- What is the performance of the students?
- What is the profile of the teacher assistants?
- How many years of experience have you teaching/being a teacher assistant at the Build-up Course Mathematics?

8. 2 Appendix B: Questionnaire

The following items were asked in the online questionnaire administered to the students in the beta testing of the third phase of the research.

1. What gender do you identify as?
   A. Male
   B. Female
2. What is your age?_______________
3. What is your nationality?
   A. Dutch
   B. German
   C. European (non-Duct/non-German)
   D. Non-European

4. What is your high school/ secondary degree?
   A. VWO
   B. HBO
   C. International
   D. Other: _________

System quality. This dimension aims to assess the overall functionality of the developed digital FLP math tool.

5. The digital tool provides high availability
   1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

6. The digital tool is easy to use
   1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

7. The digital tool is user-friendly
   1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

8. The digital tool has attractive features to appeal to the users
   1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

9. The digital tool provides high-speed information access
   1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Content quality. The items included in this dimension intend to examine the quality of the learning objectives, lesson (math definitions and terminology) and exercises.

10. The digital tool provides information (e.g., learning objectives, definitions, exercises) that is exactly what you need

1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

11. The digital provides information (e.g., learning objectives, definitions, exercises) you need at the right time
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

12. The digital tool provides information (e.g., learning objectives, definitions, exercises) that is easy to understand
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

13. The information presented in the 'lesson' is clear
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

14. The information presented in the 'lesson' is relevant
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

15. The information presented in the 'lesson' is sufficient to solve the exercises
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

16. The learning objectives presented in the digital tool are clear
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Personalised learning. This dimension aims to evaluate the extent the digital FLP math tool fit the needs of each student.

17. The exercises presented in the digital math tool are clear
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

18. The level of difficulty of the exercises presented in the digital tool is too high
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

19. The number of exercises presented in the tool is enough
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

20. The digital tool provides me multiple opportunities of learning
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

21. The digital tool allows me to progress at my own pace
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Text-Feedback quality. This dimension assess to the explanations (cues and steps) provided by the tool in the orange or green boxes after an answer is given.

22. The digital tool provides feedback that help you to understand the exercise
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

23. The digital tool provides feedback that is relevant to the topic
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

24. The digital tool provides sufficient feedback to overcome the mistakes
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

25. The feedback provided after each exercise in the digital math tool is easy to understand
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

26. The digital tool provides feedback that is clear
    1= strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

27. The feedback provided after each exercise in the digital math tool helps you to identify (possible) mistakes
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Video-Feedback quality. Aims to examine the quality of the videos presented**.** However, not all the students have access to the videos.

28. How many videos did you watch? ________

29. The digital tool provides videos that help you to understand the exercise
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

30. The digital tool provides videos that are relevant to the topic
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

31. The videos provide information to overcome the mistakes
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

32. The digital tool provides videos that are clear
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

33. The videos provide information that allow you to identify (possible) mistakes
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Benefits of the digital tool. This dimension intends to evaluate students' views regarding the benefits provided by the tool

34. The digital math tool helps you improve your performance
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

35. The digital math tool is engaging
    1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Suggestions. Please write in the box below if you have any suggestions

8. 3 Appendix C: Teacher Coordinator Interview Scheme

The scheme of the structured interview administrated to the teacher coordinator in the beta testing of the third phase of the research is presented below.

System quality. In this part of the interview, I would ask you questions regarding the system quality functionality.

- Do you think the tool was easy to use/user friendly?
- Do you think you creating an online course (lessons, exercises and feedback) is easy?
- Do you think student will find it easy to use/user friendly?
- Do you think the tool allow you to track students' progress?
- Do you think the tool provides you enough information about student's performance?
- Do you think the layout of tool (e.g., learning objectives, lesson, and exercises) is clear?

Information/Content quality: This section aims to assess the quality of the learning objectives presented, the "lesson" and the exercises.

- Do you think the learning objectives were clear and aligned with the curriculum?
- Do you think the information presented in the first slide "lesson" of the subject in the digital math tool is clear and sufficient to solve the exercises?
- Do you think the exercises presented were clear and aligned with the curriculum?

Personalised learning: This section aims ask about the adaptive items and if the DFMT meet the needs of the students

- What do you think about the level of the exercises presented?
- To move to the next level, a student needs to correctly answer four exercises in a row, do you think it is enough?
- Do you think the digital tool offers students different opportunities of learning?

Text-Feedback quality. In this section, feedback is referring to the explanations or steps provided by the tool in the orange or green boxes after an answer is given.

- Do you think the feedback provided is clear and sufficient to overcome mistakes?
- Do you think the feedback provided helps students to understand better the exercise and identify (possible) mistakes?
- Do you think the feedback provided will encourage students to improve their skills?

Video-Feedback quality (videos). In this section, questions aims to elicit the teacher's opinion about the videos created.

- Do you think the videos provided are clear and sufficient to overcome mistakes?
- Do you think the videos provided help students to understand better the exercise?
- Do you think the videos provided in the feedback after the exercise in the digital math tool help students to identify (possible) mistakes?

Benefits of the digital tool. This section aims to evaluate teacher's perspective regarding the benefits of the tool

- The digital math tool helps you improve students' performance in math.
- Do you think the tool allow teacher assistants and you to identify students' needs?
- Do you think the math tool is engaging?
- What to do you think about using this tool in the Build-up Course Mathematics?
- Do you think the integration of this tool would be smooth process?

Suggestions.

- Is there something you want to add or eliminate from the digital tool?

8. 4 Appendix D: Build-Up Course Mathematics Curriculum

Basic mathematics skills needed for the math courses of the programme.

Arithmetic

☐ be familiar with the following sets of numbers: ***natural*** numbers ($\mathbb{N}$), ***integers*** ($\mathbb{Z}$), ***rational*** numbers ($\mathbb{Q}$) and ***real*** numbers ($\mathbb{R}$)

☐ know the ***order of operations*** in arithmetic expressions, understand basic numerical properties and concepts, including ***rounding*** of numbers to the nearest whole, understanding ***prime*** numbers and finding ***factors***

☐ be able to find the ***greatest common divisor*** and the ***least common multiple*** of sets of integers

Algebraic skills

☐ be able to simplify and manipulate algebraic expressions and equations, including working with algebraic fractions and surd expressions and being able to rationalise denominators

☐ be able to work with whole-number powers and fractional powers

☐ solve linear and quadratic equations, using discriminants, the quadratic formula and cross-multiplying

☐ know how to analyse quadratic functions by ‘completing the square’

☐ be able to simplify surd expressions involving square roots and rationalise denominators

☐ be able to change recurring decimals into their corresponding fractions and vice versa

☐ be able to simplify and manipulate algebraic fractions

☐ be able to factorise algebraic expressions like quadratic expressions of the form: ax^2+bx+c

☐ be able to solve system of equations up to 3 equations in 3 unknowns

☐ be able to solve inequalities

Functions and Graphs

☐ know the concept of functions and be able to use the elementary algebraic functions (polynomials, roots and rational functions) and (basic) transcendental functions (exponential-, trigonometric-, logarithmic- and hyperbolic functions)

☐ know the basic properties of functions (e.g. ***odd*** and ***even***)

☐ be familiar with the Cartesian coordinate system and be able to work with graphs of functions (set of points (x,f(x)))

☐ be able to interpret the reverse process of a function as the ‘inverse function’; interpret the succession of two functions as a ‘composite function’

☐ be able to interpret the gradient at a point on a curve as the instantaneous rate of change

☐ be familiar with the graphs of exponential or trigonometric functions

Differential Calculus

☐ know the formal definition of differentiation ($f'=\lim_{h\to 0}\frac{f(x+h)-f(x)}{h}$)

☐ know and be able to use the following rules for differentiation: ***chain*** rule, ***product*** rule and ***quotient*** rule

☐ calculate gradients and the slopes of tangent lines

Basic Geometry

☐ know and be able to use ***Pythagoras***’ theorem

- calculate the area and perimeter/circumference of circles, triangles, squares, rectangles, cubes and spheres
- construct perpendicular lines
- express the angles of 2D geometric shapes in degrees (full circle equals 360°, right angle equals 90°)
- understand the concept of symmetry, ***line-*** and ***point*** symmetry

8. 5 Appendix E: Branching Trees

Figure E1

Branching Tree for the Product Property for Exponents

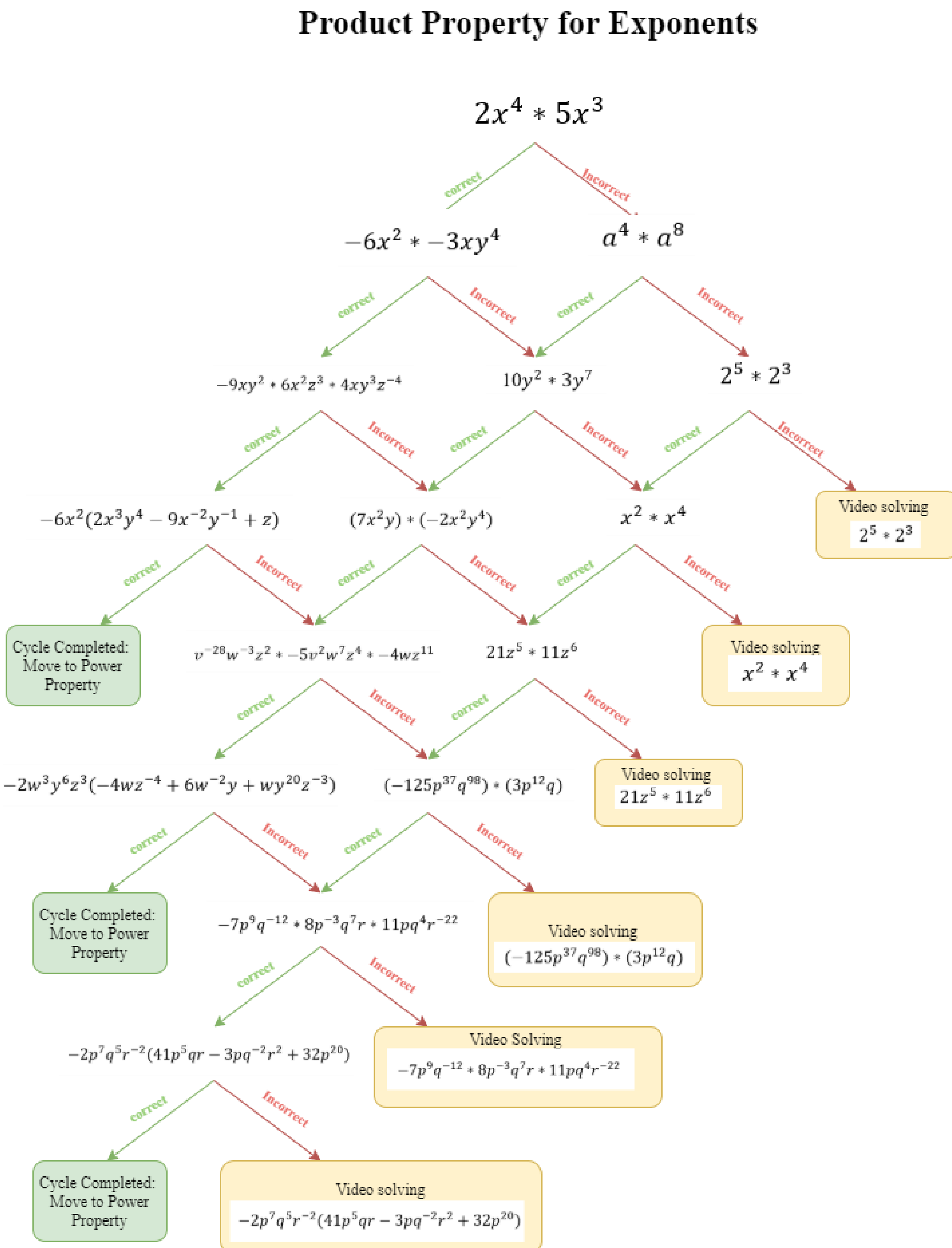


Figure E2

Branching Tree for the Power Property for Exponents

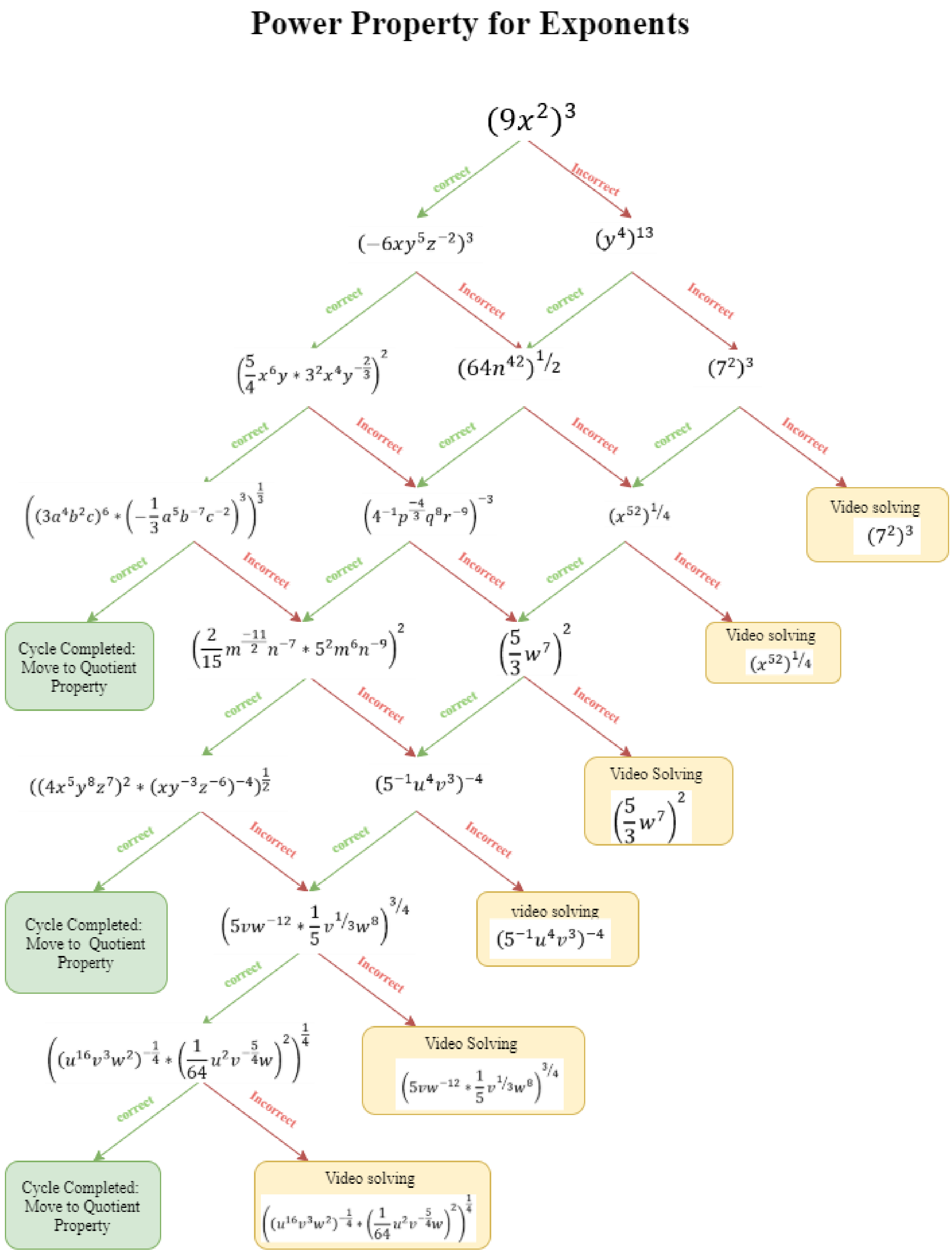
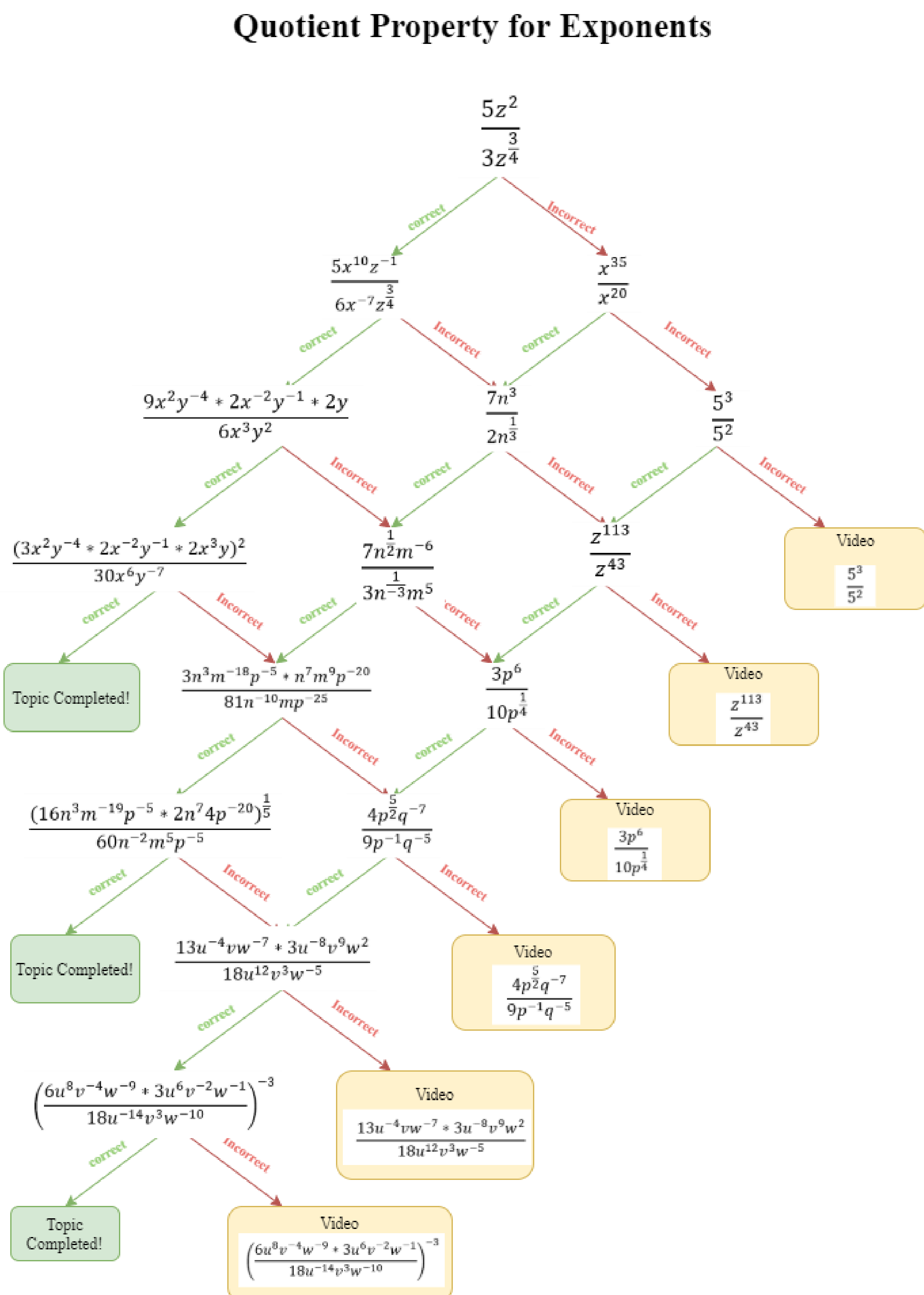


Figure E3

Branching Tree for the Quotient Property for Exponents



8. 6 Appendix F: Errors Reported in Beta Testing: Students.

Figure F1

Error #1: Missing Bar/Menu to Deliver Answer.

Figure F2

Error #2: Right Answer Being Marked as Incorrect.

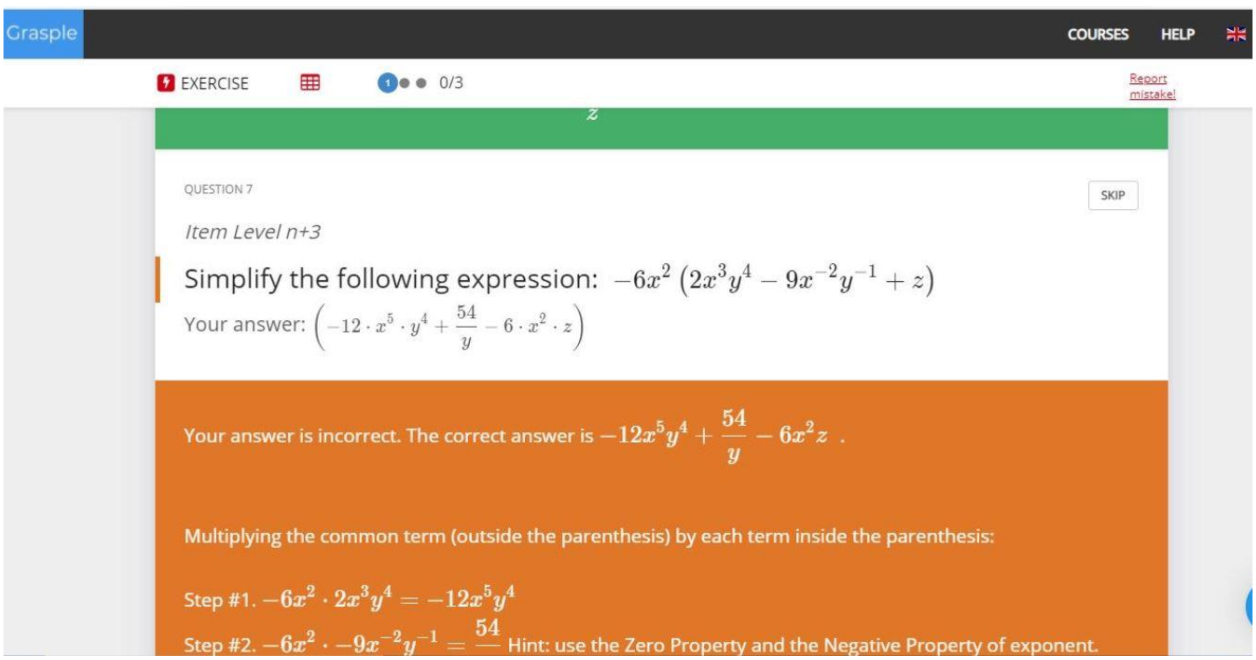


Figure F3

Error #3: Incorrect Answer Being Marked as Correct.

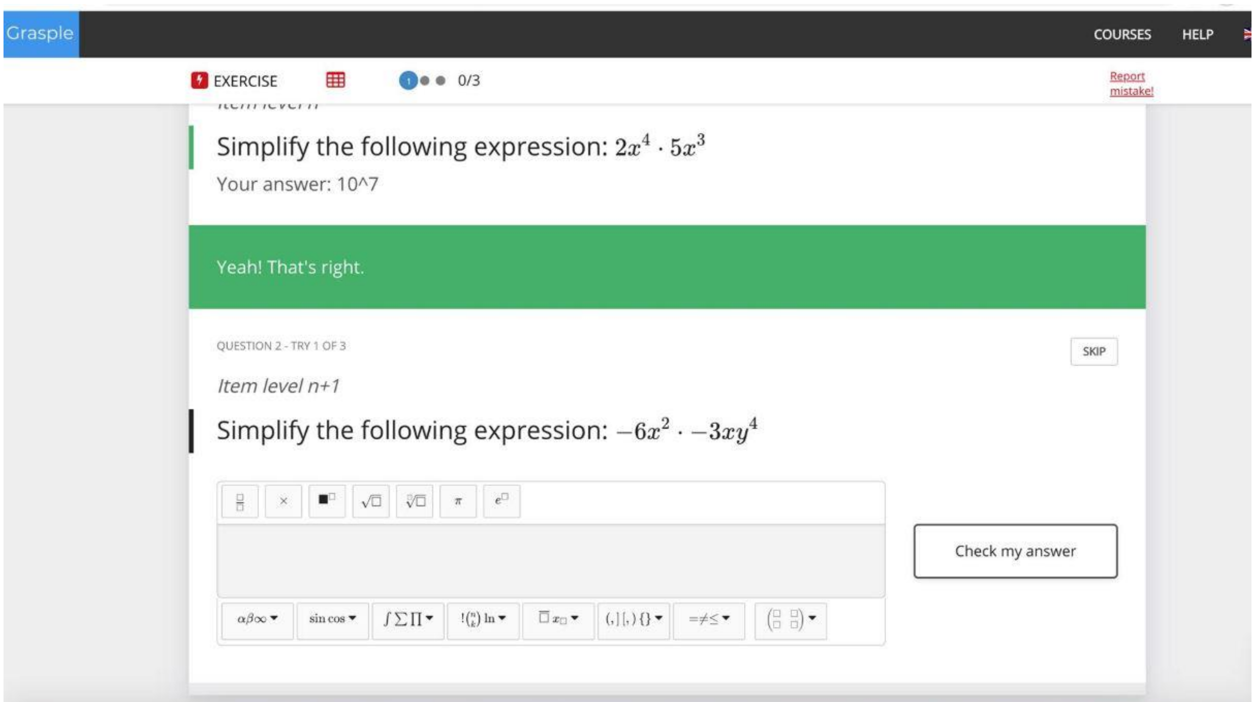


Figure F4

Error #4: Incorrect Answer Being Marked as Correct.