Weinhandl et al. *Research and Practice in Technology Enhanced Learning* (2023) 18:32
https://doi.org/10.58459/rptel.2023.18032

Research and Practice in
Technology Enhanced Learning

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Mathematics student personas for the design of technology-enhanced learning environments

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Abstract

To benefit from the quickly expanding range of new possibilities of technology-enhanced education, school systems, schools, and teachers need to adapt quickly. Conversely, the needs of students and teachers in a technology-enhanced classroom require technology developers to provide and improve suitable technologies. In this paper, we aim to show how to make the professional knowledge of mathematics teachers accessible to developers of technologies and also to teacher trainers and trainees by the use of student personas, i.e., portraits of archetypical students with particular characteristics and needs. We have collected qualitative data from pre-service and in-service mathematics teachers in Austrian academic upper secondary schools about the characteristics and needs of their students. We have analysed these data using a grounded theory approach to derive demands of students on technology-enhanced learning environments (TELEs). We have identified and presented five personas, each with specific demands on TELEs, to represent this target group. By introducing this approach that combines techniques from mathematics education research and from user experience research, we are able to represent user groups of a mathematics technology-enhanced learning environment in a more relatable way than was previously possible. These relatable representations of students in Austrian academic upper secondary schools could be of particular importance for developers of technology-enhanced learning environments for teaching and learning mathematics. The methodology presented in this paper is adaptable to other contexts.

Keywords: Educational technology, Grounded theory, Mathematics education, Personas, Secondary education, Student characteristics

Introduction

The digital revolution triggered by the emergence of computers and digital technologies has changed and continues to change how people gain access to information and communicate with each other. The impact of digital technologies on education is substantial. Their affordances have brought with them an unwieldy range of new possibilities, especially for teaching and learning mathematics (Inayat & Hamid, 2016). These new possibilities require developers of digital technologies to align their commercial and economic interests with the responsibility of designing technologies that support the development of students' competencies in the best possible way. Educational research plays a pivotal role in guiding this transformation, pointing out opportunities and potential risks for education and providing recommendations for shaping technology-enhanced learning environments (TELEs). Modern educational technologies have been frequently used for the teaching and learning of some mathematical concepts in particular, for example, mathematical functions (e.g., del Cerro Velázquez et al., 2021), mathematical modelling (e.g., Greefrath, 2011), or geometry (e.g., Laborde et al., 2006). Some of the technologies used in this context have a long tradition, such as dynamic geometry environments (Laborde et al., 2006), while others have emerged recently, such as augmented reality (del Cerro Velázquez et al., 2021). Typical affordances of technologies in this context are, for example, that the representation of mathematical concepts can be easily changed (e.g., to represent a function as a graph, in tabular form, or in function notation), that mathematical operations and calculations can be performed, or that the real world and abstract mathematical concepts can be connected more easily. The difference between the mere use of specific mathematical technologies and teaching and learning in mathematical TELEs is, on the one hand, that different mathematical technologies are combined in TELEs to deepen knowledge about mathematical concepts and mathematical competencies. On the other hand, mathematical TELEs facilitate that both mathematical technologies, such as dynamic geometry environments or computer algebra systems, and general, subject-independent technologies are combined. Through such use of technologies, how and what is learnt in mathematics classrooms can be changed (Sinclair, 2020). In order to develop such mathematical TELEs, which improve the learning of mathematics in the best possible way, it is necessary, among other things, that the needs and characteristics of mathematics students are known and then taken into account when developing mathematical TELEs.

The availability and affordances of technologies, the beliefs of teachers on the use of technologies in the classroom, and the professional development of teachers are key factors for the success of TELEs; see, e.g., the literature review in Kopcha (2012).

In this work, we propose an approach that integrates techniques from user experience research (UX research) into educational research to create a common ground for technology developers, teachers, and teacher educators. With this approach, we aim to identify patterns in data on school students and represent them in a way that makes them more easily comprehensible and processable for developers of TELEs.

Specifically, we use such an approach in this work to derive recommendations for designing TELEs for teaching and learning mathematics. Thereby, we aim to facilitate the inclusion of the needs of students and formal requirements in the development of educational technologies for mathematics. In our study, we focus on school students of academic upper secondary schools in Austria. According to the Austrian School Organisation Act (SchOG, Abschnitt II, § 34 (1)), the purpose of academic secondary schools (Allgemeinbildende höhere Schulen) is "to provide students with a comprehensive and in-depth general education and, at the same time, qualify them to enter universities" (Federal Ministry for Digital and Economic Affairs, 2022, translated by the authors). The curriculum for these schools mandates the use of higher-order technologies both in general and specifically in mathematics (Federal Ministry for Digital and Economic Affairs, 2021b). Specifically, our research addresses the following research question:

What are the requirements of mathematics students in academic upper secondary schools in Austria for a technology-enhanced learning environment?

To identify students' demands and needs related to TELEs, we use persona development techniques from UX research and constructs of educational psychology to create portraits of fictional upper secondary school students that represent groups of students with common characteristics and common demands and needs for TELEs. This scientifically generated information should support designers of TELEs to meet the requirements of students and could thereby open a new door in terms of scientific knowledge as well as practical development of TELEs and a valuable supplement to existing approaches in educational psychology.

Theoretical background

By providing features that promote learning at an individual pace and level, educational technologies can mediate between curricular requirements on the one hand and individual needs and potentials of learners on the other hand. The integration of technologies is mandatory in Austrian academic upper secondary schools (Federal Ministry for Digital and Economic Affairs, 2021b). In this paper, we do not consider educational technologies by themselves but investigate their potential role in creating a *technology-enhanced learning environment* (TELE). Specifically, we aim to identify the requirements learners have on TELEs and derive from them design recommendations for educational technologies. These requirements are identified by using persona development techniques drawn from UX research. This novel combination of techniques and knowledge from educational research and from UX research should contribute to individualisation in secondary school mathematics education and lay the foundation for further scientific investigations. We have identified five personas, i.e., descriptions of fictional users of technologies that represent groups of students with comparable characteristics and needs, and present them in this work. Before we detail our methodology, we expand on the definition of TELEs and the theoretical constructs used to create personas in this work.

Technology-enhanced learning of mathematics

Each of the first two decades of the 21st century has been described as a period of fundamental change for teaching and learning mathematics on account of the emergence of technology-enhanced learning and TELEs (e.g., Anderson et al., 2014; Fowler et al., 2021; Kurvinen et al., 2020; Ng et al., 2020). We highlight the increasing dynamics of scientific research on the use of TELEs in the classroom (e.g., Fowler et al., 2021; Kurvinen et al., 2020; Ng et al., 2020) and on the development of digital tools and learning environments (Anderson et al., 2014; Steffens et al., 2015). Kurvinen et al. (2020) point out that the number of computers and personal smart devices is increasing rapidly, changing the ways we interact and work. Gadanidis and Geiger (2010) explain that web technologies have already become a ubiquitous tool and that we have moved "from thinking about technologies to thinking with technologies". The ubiquity of the web and digital technologies has mounted pressure on schools and educators alike to digitalise learning (Gadanidis & Geiger, 2010; Kurvinen et al., 2020).

The abundance of available digital technologies has given rise to a diversity of descriptions and definitions of technology-enhanced learning. Law et al. (2016) define technology-enhanced teaching and learning as "integrating the use of digital technology into the learning and teaching process to improve the quality of learning outcomes". Kurvinen et al. (2020) view mathematics TELEs as comprising specific educational software, apps, or games for learning mathematics; they exclude general-purpose software such as a word processor or a calculator from the definition. Fowler et al. (2021) have investigated settings in which TELEs are used to implement constructivist or social constructivist approaches to learning, meaning that students gain new knowledge and skills through collaborative problem solving. Keppell et al. (2015) conclude that best practice technology-enhanced learning provides a learner-centred environment that takes into account learners' attitudes, knowledge, perspectives, or biases towards learning. Also Kurvinen et al. (2020) see value in TELEs that provide the required support for students to proceed at their own pace. Similarly, Ustunel and Tokel (2018) value TELEs as scaffoldings for students to learn individually and effectively through "interactive and iterative learning environments". A similar conclusion is reached by Polly et al. (2021) who expect TELEs to be particularly fruitful when technologies enable students to engage in activities which go beyond drill and practice and which foster higher-order thinking. Lee and Choi (2017) also focus on higher-order thinking in TELEs and identify deep learning approaches, as opposed to surface learning approaches, as predictors of higher-order thinking. They conclude that students tend to adopt deep learning approaches more frequently in a TELE than in other learning environments. Rodríguez et al. (2012) summarise that integrating digital tools into teaching is no longer a technical matter but depends primarily on the purpose for and on the way in which digital tools are used in teaching and learning. These are important perspectives to consider in the design of TELEs. Even though TELEs have received much attention in research, designing and creating settings that effectively and efficiently promote learning continues to pose a challenge for educators and researchers (Chen & Woolcott, 2019). The potential of teachers' knowledge for the design of technology-enhanced learning is well documented (Kim, 2019).

To make the design process of TELEs fruitful and to enable teachers to act as designers of TELEs, detailed knowledge about the target group of TELEs – in our case mathematics students in upper secondary schools – is essential. Personas provide an opportunity novel in this context to capture students' characteristics, goals, and needs. At the same time, personas enable researchers to learn about subgroups of students with their varying characteristics, rather than to evaluate averages and extreme cases within the student population.

Learner goals, needs, and motivations

Cooper (1999) introduced personas as a tool to guide the development of marketable products by the goals and needs of target users as reported by experts. In this work, personas are used to represent the *goal orientations* and *basic psychological needs* of students to guide the design of TELEs. The development of these personas is informed by teachers. Unlike specific goals and personal preferences, goal orientations and basic psychological needs reflect the motivational dispositions of students towards learning (Dickhäuser et al., 2016). Knowledge and consideration of these dispositions are essential for the success of learning environments (see, e.g., Hall & Götz, 2013).

To classify the goal orientations and basic psychological needs of students and to conclude on the underlying motivational dispositions, we use the well-established frameworks of *achievement goal theory* and *self-determination theory* from educational psychology.

Achievement goal theory

Achievement goal theory is a well-explored construct in educational psychology to determine how intrinsically or extrinsically motivated a learner is (Nicholls, 1984). This construct distinguishes categories of self-evaluation that were labelled *task-involved* and *ego-involved* by Nicholls (1984) and *learning-oriented* and *performance-oriented* by Dweck (1986), respectively. In this work, following Elliot and Harackiewicz (1996), we speak of *mastery goals* to refer to learning-oriented goal orientation, and *performance goals* to refer to performance-oriented goal orientation. According to Elliot and Harackiewicz (1996), learners with high mastery goals aim at learning as much as possible on their initiative, i.e., mastery goals indicate intrinsic motivation. Learners with high performance goals aim to satisfy external expectations or make socially recognised achievements such as good grades or performing well compared to others (Elliot & Harackiewicz, 1996). Their goal is not to master the material but to prove themselves and get rewarded by drawing others' attention or praise. Elliot and Harackiewicz (1996) further categorise performance goals into *performance-approach goals* and *performance-avoidance goals*. While performance-approach goals indicate that striving for high performance (i.e., achieve good grades, receive praise from others, do well compared to others) originates from intrinsic motivation, performance-avoidance goals reflect a learner's attitude to avoid failure and are associated with passiveness and anxiety, which undermines intrinsic motivation (Elliot & Harackiewicz, 1996).

Self-determination

According to the *self-determination theory* of Deci and Ryan (2008, 2015), the satisfaction of basic psychological needs is critical for general well-being as well as for stimulating interest and engagement. They identified the experience of *autonomy*, of *competence*, and of *social relatedness* as the three key factors for psychological well-being in a given context. How strong the experience of each one of these factors has to be for well-being, interest, and engagement depends on the individual (Deci & Ryan, 2008).

By using personas, the theoretical considerations of achievement goal theory and of self-determination theory should be brought to life and the theoretical constructs of these theories should be related to real-life mathematics students.

TELEs fostering student motivation

The psychological constructs outlined above are used in our work to assess the learners' attitude towards learning and determine the role that technologies should take to support their learning. Grassinger et al. (2019) argue that motivation plays a crucial role in effective learning. Therefore, they consider fostering motivation as a key approach to improve the quality of learning and suggest three ways to realise the promotion of motivation in students: (a) communicating the value of learning activities and promoting expectancy of success; (b) satisfying the need for autonomy, competence, and social relatedness; (c) setting goals and establishing a goal-driven working atmosphere. According to Grassinger et al. (2019), promoting the value of learning activities can, for example, be realised by explaining the choice of learning activities or connecting the content with the students' interests. The need for autonomy can be satisfied by, e.g., involving students in setting learning goals; the need for competence can be satisfied by, e.g., giving feedback; and the need for social relatedness can be satisfied by, e.g., group work. A goal-driven work climate can be established by, e.g., applying the *SMART guideline*, which suggests framing goals in a way that they are specific, measurable, ambitious, realistic, and time-bound. An extensive list of approaches that foster motivation is given in Grassinger et al. (2019, pp. 221 ff.).

We expect that TELEs can offer affordances that cater to individual needs to foster motivation and, eventually, to improve the quality of learning. This expectation is based on Dunn and Kennedy's (2019) finding that students' engagement in technology-enhanced learning predicts academic achievement. Therefore, we use a learner's achievement goal orientation and the degree of self-determination to identify which kind of support is needed in particular and which affordances a TELE should offer so that the learner engages in technology-enhanced learning.

Methods

To identify the demands of mathematics students in academic upper secondary schools in Austria on technology-enhanced learning environments, we have used new techniques for developing personas; analyses were based on grounded theory approaches (Charmaz, 2006; Glaser et al., 1968; Woods et al., 2016).

Persona development techniques

Personas are fictional archetypical users of a system that can be used when designing a technology-supported or technological system (Antle, 2008; Minichiello et al., 2017; van Rooij, 2012). When developing personas, special attention is paid to the needs, wishes, and technical expertise of potential users (Lilley et al., 2012; van Rooij, 2012). Unlike other descriptions of users of a system, which are often impersonal, in persona development the characteristics and needs of similar users of a system are condensed into one realistic fictional archetypical user. Such a user has a name, a picture, and additional information reproduced in tabular form or detailed written form (Lilley et al., 2012; Maness et al., 2008; van Rooij, 2012; Zaugg & Rackham, 2016). Personas in tabular form are called *dashboard personas* (Minichiello et al., 2017). One goal of using persona techniques is that typical user groups of a system become realistic. This characteristic of personas should make it easier for designers of technologies and of pedagogical settings to empathise with different user groups (Ferreira et al., 2015; Sundt & Davis, 2017; van Rooij, 2012; Vorvoreanu et al., 2016).

To develop personas, one should collect as much and as rich data on potential users of a system as possible (Maness et al., 2008; Miaskiewicz et al., 2008). Qualitative and quantitative data as well as primary and secondary data are commonly used in the persona development processes (Sundt & Davis, 2017; Volentine et al., 2017). According to Sundt and Davis (2017), primary data are data collected directly from potential users of a system. Secondary data are data collected about potential users of a system from sources other than themselves, usually by people who provide information about them. A classical tool for collecting qualitative information is by interview (Zaugg & Rackham, 2016; van Rooij, 2012). In our study, interviews were conducted with experts about potential users of a system, following Antle (2008). Another way of collecting qualitative or quantitative information is by web surveys (van Rooij, 2012). Web surveys expand the geographical range when recruiting respondents. This leads to higher reliability and more specialised foci in data analysis. Quantitative data in persona development can be collected directly from potential users or about users from other sources such as experts. Also, official administrative databases or statistics on the user group or general population can be used (Volentine et al., 2017; Vyas et al., 2006).

According to Cooper (1999), the development of personas should be driven by the goals of the target users. To render our results suitable for supporting designers in transforming the needs and – frequently implicit – requirements into technologies with features that cater to these needs and requirements (Cooper, 1999). Following this recommendation, we put a focus on the achievement goals in our data analysis.

We combined persona development techniques and grounded theory approaches to identify what students in academic upper secondary schools in Austria require from a TELE in their mathematics classes.

Target group

The target group of our study are students in Austrian academic upper secondary schools (14-18-year-olds). These students prepare for a compulsory, written school-leaving exam in mathematics that is standardised and set centrally. This exam contains mathematics problems whose solutions require the use of higher-order technologies (Federal Ministry for Digital and Economic Affairs, 2021a, § 18). To prepare students in the best possible way for this exam, the curriculum (Federal Ministry for Digital and Economic Affairs, 2021b) requires that students be trained not only in the subject matter but also in the use of permissible aids, which includes technologies for solving maths problems. Considering these curricular requirements and given that the students in upper secondary schools spent long periods in distance learning in the school years 2019/20 and 2020/21, it can be assumed that this group of students has ample experience in the use of technologies to solve mathematical problems as well as in working in TELEs.

Data collection and analysis

The collection and subsequent analysis of data was carried out in three steps. In the first step, relevant administrative and statistical data on academic upper secondary school students were identified in repositories of the national statistical agency and national education reports. These data informed the subsequent collection of qualitative data. In the second step, qualitative data on the goals and needs of academic upper secondary school students with regard to learning mathematics, including requirements on a TELE, were collected from teachers. Personas were developed based on these qualitative data. In the third step, the personas were refined and validated.

Data collection

The quantitative data in our study were taken from Statistics Austria (2021), the National Education Report 2015 (Bruneforth et al., 2016), and the National Education Report 2018 (Breit et al., 2019). They were used to frame the collection of qualitative data on academic upper secondary school students. The qualitative data used in our study were collected from teachers who reported goals, needs, emotions, and strategies of a typical school student with regard to learning mathematics in 13 open-ended questions (e.g., "What are the goals of the student in your maths class and what strategies does the student use to achieve them?", "What challenges or problems does the student face when learning mathematics?"). The sample of teachers was framed to reflect aspects of the statistical and administrative data. Accordingly[a], when inviting teachers to participate in our study, teachers from schools in rural areas and in urban areas were nearly equally distributed; roughly 60% were female and roughly 40% were male. Among the mathematics teachers invited for our study, the majority are mid-career and end-of-career teachers. These two groups form the bulk of teachers in academic secondary schools in Austria. Care was taken to involve pre-service teachers at the beginning, in the middle, and at the end of their academic training in roughly equal proportions.

As a first step, the web survey of our study was sent to these groups of pre-service and in-service academic upper secondary school mathematics teachers. To keep participation of pre-service and in-service teachers in our study high, we did not ask for personal data. In selecting the mathematics teachers to validate and improve the personas developed in our study, a selection was made according to the aforementioned criteria. In total, our web survey on characteristics of mathematics students and requirements of mathematics students of an academic upper secondary school in Austria for a technology-enhanced learning environment was sent to 56 in-service teachers and 139 pre-service teachers. Of these, 13 in-service mathematics teachers and 61 pre-service mathematics teachers completed the web survey. We used the responses of sufficient quality in our qualitative analysis.

Data analysis

The basis for the data analysis presented in this paper are data from pre-service and in-service mathematics teachers about secondary school students as described in the previous subsection and data from personas developed in a previous project (Weinhandl et al., 2022) where the focus was to identify student profiles based on their goals, needs, and emotions with regard to learning mathematics. To analyse the data, we proceeded in three steps that we refer to as *coding*, *clustering*, and *merging*.

Coding. In the first step, the two first authors applied the technique of open coding (Corbin & Strauss, 1990). They each individually identified words and phrases in the mathematics teachers' descriptions of their students and coded them according to the various manifestations of achievement goals (mastery, performance-approach, performance-avoidance) and basic psychological needs (perceived autonomy, competence, and social relatedness). While producing these codes, following the recommendations of Corbin and Strauss (1990), the researchers constantly compared intermediate results with the raw data. The two authors then met to compare the codes they had each produced and discussed disparities until consensus was reached. Regarding achievement goals, for example, "wants to learn as much as possible" was coded as a mastery goal orientation, "wants to have straight A's" was coded as a performance-approach goal orientation, and "wants to pass with as little effort and commitment as necessary" was coded as a performance-avoidance goal orientation. Regarding self-determination, for example, "independent study" was coded as a need for autonomy, "wants to excel in exams" was coded as a need for competence, and "appreciation by peers and teachers" was coded as a need for social relatedness.

Clustering. In the second step, each of the two first authors identified the predominant goal orientations as well as the degrees of perceived autonomy, competence, and social relatedness in each of the student descriptions based on the codes generated in the first step. They each clustered the student descriptions based on the predominant manifestations of achievement goals and basic psychological needs. The two first authors then discussed their clusters and refined them to a joint result. For each of the resulting clusters, each of the two first authors derived requirements on a TELE to increase the effectiveness of learning. These requirements were described in prose.

Merging. In the third step, the researchers discussed the requirements on TELEs they had each assigned to each cluster of student descriptions in the second step. They merged them into agreed-upon descriptions of requirements on TELEs for each cluster. Finally, a persona representing each cluster of student descriptions was created by further adding personal information based on the raw data and the personas developed previously in Weinhandl et al. (2022). The resulting personas are presented in the following section.

Results

Using techniques from UX research related to persona development as well as from grounded theory, we identified five distinct personas to represent students in Austrian academic upper secondary schools with regard to mathematics. These five personas have different goals, needs, and fears when it comes to learning mathematics and different requirements as to technology-enhanced learning environments. To our knowledge, our study is the first to combine educational research with persona development techniques from UX research with focus on upper secondary mathematics education. The personas resulting from our study are presented in dashboard form. To render them more vivid, we added to each persona a picture and personal information. Such vivid representations of potential users of a system could facilitate empathy with these potential users in the design process of a technological system, pedagogical setting, or training of pre-service and in-service mathematics teachers. The personas could be conducive to both research and practice in the field of TELEs. From the 74 descriptions of students that were collected 67 were used to create the personas. The remaining seven descriptions either were too superficial or were single outliers and did not fit any of the personas that developed during the data analysis. The following five personas of mathematics students have evolved from our analysis.

Johannes Friedrich is representative of school students with a clear mastery orientation and who are familiar with technologies such as dynamic geometry software or computer algebra systems. These students aim at gaining as much knowledge as possible and obtain the best grades with little effort. They do not focus on performance but on their individual progress. A TELE can support them, for example, by providing quality materials. Regarding basic psychological needs, they seek opportunities to connect with experts and to become part of a community in which discussion about mathematics on their level is possible. A TELE can help them get in touch with experts and with people who are at the same high mathematical level in order to satisfy their need for social relatedness. Feedback can promote their perceived competence, on the one hand to be reassured when coming up with a solution, and on the other hand to get an idea how to continue when they are stuck with a problem. To experience autonomy, a TELE can support them by offering materials at different levels from which they can choose. The full description of Johannes Friedrich can be seen in Figure 1.

Johannes Friedrich

Johannes is an interested, mastery-oriented and intrinsically motivated student who wants to gain as much mathematical knowledge as possible and to perform as well as possible. Johannes likes to learn, understand, and use mathematical concepts covered in class and mathematical concepts that go beyond what is learnt in class. What annoys Johannes about maths classes is that teaching and learning mathematics are strongly geared towards preparation for exams and answering standardised exam questions.

Requirement for a technology-enhanced mathematics learning environment

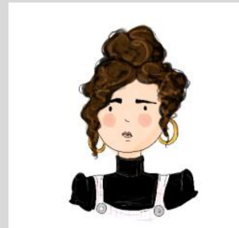
In a technology-enhanced mathematics learning environment, Johannes would like to have the opportunity to receive extensive information about mathematical concepts covered in mathematics lessons and information about content that goes well beyond what is presented at school. Johannes expects the technology-enhanced learning environment to provide reliable information and quality-assured technological tools when searching for mathematical content and support tools. Johannes is also interested in applying mathematical concepts that are not covered in lessons. If he cannot proceed, he does not want the entire solution to be revealed right away but rather to receive a hint that he can use to solve the problem on his own. After coming up with his solution, he wants to be reassured by checking the correct solution. Furthermore, the technology-enhanced learning environment should allow Johannes to exchange ideas and thoughts with other people interested in mathematics. The structural design of the technology-enhanced learning environment is less important for Johannes, as he is nimble in navigating through digital environments as long as navigation is somewhat intuitive. He uses technologies as support tools to change between numeric and graphic representations, receives hints when he is stuck in solving a problem, and reassure if his solution to a problem is correct. His main tools, however, remain paper and pencil. Johannes is highly intrinsically motivated and hardly needs to be encouraged by the TELE. However, he expects the TELE to be of practical utility, i.e., he wants content to be neatly arranged and easy to be found, but he does not want features that distract him from the actual content.

Fig. 1 Persona “Johannes Friedrich”

Aurelia Höfinger represents school students who view mathematics as a prerequisite for something they consider important (e.g., studying at university) and technologies as a valuable tool for fulfilling this prerequisite. These students are motivated to perform well in mathematics and require confirmation that they master this prerequisite. They are clearly performance-approach oriented. Regarding their basic psychological needs, the satisfaction of their need to perceive themselves as competent is most important for them. In this regard, a TELE can support them by providing feedback on their solutions and by displaying the progress on current goals. For perceiving themselves as autonomous, external resources that they can choose from should be provided by the TELE. The full description of Aurelia Höfinger can be seen in Figure 2.

Aurelia Höfinger

Aurelia is a student oriented towards performance and proving her skill. It is essential to Aurelia that she gets excellent grades on mathematics exams and in her school report. To reach this goal, Aurelia invests a lot of time in studying. In class, Aurelia is proactive when she believes that her efforts will have a positive effect on her grade. All mathematical problems or mathematical applications that go beyond the school material unsettle Aurelia.



Requirement for a technology-enhanced mathematics learning environment

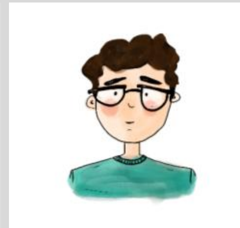
Aurelia benefits from a technology-enhanced mathematics learning environment that offers many exercises for practice. These exercises should support Aurelia in targeted studying for exams. When Aurelia studies in a technology-enhanced mathematics learning environment, she also expects that there will be instant feedback on whether problems have been solved correctly or not. If Aurelia cannot solve a problem, she wants specific information about the aspect that she could not handle properly. If tasks are distributed and collected via the technology-enhanced mathematics learning environment, Aurelia would have the tasks and the respective due dates displayed directly when entering the learning environment. Furthermore, the technology-enhanced learning environment should remind Aurelia of incomplete pending homework and upcoming exams. Since permanent pressure to perform appears to affect Aurelia psychologically, again and again, switching this reminder function off should be possible. Aurelia also hopes to receive bonuses for diligent work and for using the technology-enhanced mathematics learning environment. She enjoys engaging in challenges of an appropriate level and being rewarded for successfully completing them. These rewards (e.g., badges, scores) should be displayed in her account, and Aurelia would like a leader board where everyone can see and compare to the fellow students their score that reflects the effort and the success in the use of the environment. Mathematical tasks or problems that are not in the curriculum can also be part of the technology-enhanced mathematics learning environment. Still, what is relevant for her mathematics classes and exams should be clearly marked.

Fig. 2 Example Persona "Aurelia Höfinger"

Manuel Winkler represents school students who have great potential in mathematics that they do not live up to due to a lack of motivation or other, competing interests. These students adopt attitudes to avoid failure. They hope to save time and effort by the use of technologies. The TELE should provide incentives for these students to do mathematics. To satisfy the students' need to perceive themselves as competent, TELEs should foster in them a sense of achievement when a goal has been reached. The full description of Manuel Winkler can be seen in Figure 3.

Manuel Winkler

Manuel is a mathematically gifted student who invests little effort in studying mathematics. He shows low interest in mathematics and uses any means to avoid failing and to get past exams and assessments. Manuel likes mathematics lessons when standard problems are dealt with, which he can solve easily and quickly. Manuel also likes it when he knows precisely how much effort has to be invested for which grade. He deals with mathematics more intensively only shortly before exams.



Requirement for a technology-enhanced mathematics learning environment

A technology-enhanced learning environment should guide Manuel through to compensate for problems in self-organisation and stimulate the development of self-organisation skills. Motivating elements should help Manuel work continuously and avoid cramming before exams.

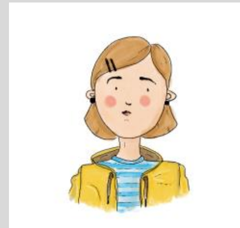
Therefore, Manuel would like a technology-enhanced mathematics learning environment with preselected exercises tuned to his current level of knowledge. As self-organisation is a challenge for Manuel, the learning environment should divide the pending work into concrete goals. He needs to keep track of his current goals related to learning mathematics and needs his progress to be visible (e.g., progress bars). Manuel would also like to easily find compact information on previous classes in the learning environment to review the materials before exams. Furthermore, Manuel would like a technology-enhanced learning environment to provide him with information about his current grades. Additional tasks to deepen understanding of mathematical concepts can be part of the technology-enhanced mathematics learning environment. Still, these tasks should be located at the back level of the learning environment. Manuel will only visit this additional material anyway if he is bored and if the mathematics problems that are not part of the curriculum are presented entertainingly (e.g., videos, games).

Fig. 3 Persona "Manuel Winkler"

Diana Markovic represents school students who put great effort into learning mathematics but frequently experience failure. They are enduring but have rather low self-confidence. They prefer familiar, easy-to-use technologies that they can rely on. They show high performance goal orientations. In order to promote their self-confidence, their need to perceive themselves as competent should be addressed by TELEs. The full description of Diana Markovic can be seen in Figure 4.

Diana Markovic

Diana invests a lot of time in studying mathematics and mathematical concepts. Despite this high investment of time and effort, Diana usually achieves poor grades in exams. To pass the exams, she tries to develop schemes for herself to solve the mathematical problems in the exams. Diana rarely asks classmates for help when studying because she fears that she might embarrass herself in front of her classmates.



Requirement for a technology-enhanced mathematics learning environment

Diana needs a technology-enhanced mathematics learning environment where various standard problems with a clearly marked level of difficulty are offered. When Diana uses a technology-enhanced mathematics learning environment, she also wants immediate feedback on whether a problem has been solved correctly. If Diana cannot solve a problem, she wants information about the correct solution and a scheme for solving the problem. If using the solution scheme is not sufficient for Diana to understand how to solve the mathematical problem, she wants to ask for help anonymously. To have her anonymity preserved but still have the chance to prove herself, Diana wants to do voluntary bonus exercises that she can attempt to solve but that are not rated unless solved correctly. The structure of the mathematics learning environment should be as simple as possible. Diana would also like the technology-enhanced mathematics learning environment to contain only information, tasks, and problems relevant to the mathematics classes at school. In her opinion, dealing with mathematical tasks or problems not in the curriculum is reserved for mathematically talented students.

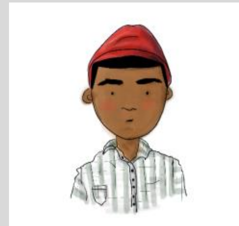
Fig. 4 Persona "Diana Markovic"

Dominik Ghali represents school students who care much about how they are perceived by others – both inside and outside the classroom. They consider mathematics as important but are not motivated to do mathematics. At the same time they do not want be seen as underachievers by their teachers and classmates. Their goals are performance-oriented.

For these students, the satisfaction of their need for competence is important. A TELE can reassure them by confirming that, where applicable, they have performed sufficiently well. The full description of Dominik Ghali can be seen in Figure 5.

Dominik Ghali

Dominik would like to take up a technical profession later on and knows that it is vital to deal with mathematical concepts of classes. Despite his technical career aspirations, Dominik spends his time in the classroom and especially in his leisure time trying to impress his classmates. Dominik only deals more intensively with mathematical concepts when exams are imminent. Dominik notices that this approach increasingly leads to problems and poor grades. If Dominik is stuck in exam preparations or in the last mathematics lessons before exams, he wants immediate help from the teacher or classmates.



Requirement for a technology-enhanced mathematics learning environment

Dominik only rarely uses the technology-enhanced mathematics learning environment and therefore wants it to be structured as simply as possible. Information and tasks on the current subject matter should be immediately apparent, and it should be recognisable which information and tasks are relevant for the next exam. Dominik requires the learning environment to provide explanations and sample solutions that he can review when he is stuck. Since Dominik is interested in mathematics and technology but has little motivation to study, he likes entertaining learning opportunities. Dominik believes such entertaining and gamified learning opportunities should definitely be part of the technology-enhanced mathematics learning environment. He occasionally visits the video channel of a physics professor who explains physics and mathematics concepts lively and with a great deal of wordplay. Likewise, Dominik finds online mathematical tinkering games cool. Dominik finds these tinkering games even cooler when he can duel with his classmates.

Fig. 5 Persona "Dominik Ghali"

The results of our study show that students in Austrian academic upper secondary schools wish for comprehensive learning materials, including concrete tasks to support their learning and practice of basics as well as for in-depth study and challenge that go beyond the curriculum. The development and availability of TELEs providing such materials should make it easier to build and hone mathematical competencies and to prepare for exams including, for example, the standardised Austrian school leaving exam. Moreover, TELEs should include only materials that satisfy high subject-specific pedagogical standards. For each task in a mathematics TELE, hints as well as fully worked solutions should also be provided. Means for communication both with peers and with the teacher should be embedded. For example, it should be possible to announce tasks and submit homework via the TELE. Furthermore, the TELE should provide incentives through a reward system. This reward system could be by way of bonus points which may be part of formal assessment as well as leader boards, badges, or other forms of acknowledgement that are not part of the formal assessment.

Discussion

The personas developed in our study and described in the previous section represent five typical sets of requirements of students in Austrian academic upper secondary schools with regard to TELEs in mathematics education. Technologies can serve mathematics education in particular as they can "strengthen the activity of doing maths" by allowing for experimenting and visualising (Hegedus et al., 2017). Moreover, highly complex aspects can be outsourced to technologies, which enables teachers to address aspects of abstract and advanced topics already at an early stage (Hegedus et al., 2017). By making the students' requirements for technologies tangible by the use of personas, technology developers and teachers can design TELEs attuned to the recommendation of Kurvinen et al. (2020) that TELEs should enable all students to work individually and at their own pace. While students who are intrinsically motivated to study mathematics may use TELEs mostly to look up specific mathematical content or to check results (e.g., persona "Johannes Friedrich"), other students may benefit from TELE functions that provide guidance, for example by displaying pending tasks and their progress on each of them (e.g., persona "Manuel Winkler"). The personas developed in this study account for these different requirements in individualised learning.

We expect that the personas developed in this project will be particularly useful for the following three target groups. Firstly, the personas can be a valuable resource for *developers of educational technologies* to render their designs student-centred. They can make developers aware of how students with different goals and needs can be supported by technologies with regard to content, motivation, and organisation. This should facilitate making appropriate decisions on the design and features of educational technologies. Secondly, personas can support *teacher educators* to convey expertise on the affordances of technologies and on how to integrate technologies into classrooms to create TELEs. Teacher educators play a decisive role for providing teachers with a range of methods they can draw from when planning and designing their lessons (e.g., Tondeur et al., 2017). Therefore, aspects of integrating technologies into classrooms should be addressed in teacher education and professional development. According to Scherer et al. (2019), training teachers in the use of educational technologies increases their self-efficacy when working with technologies in their classrooms. This suggests that personas can be a valuable resource for fostering confidence in pre-service and in-service teachers in applying technologies and in designing TELEs. Thirdly, personas can support *teachers* in combining the affordances of technologies with the recommendations received from teacher educators to design TELEs adjusted to the individual requirements of their students. In particular, teachers can use personas to choose suitable technologies for their classrooms and ways of integrating them to the benefit of their students' learning.

The demand on a TELE for school-based mathematics learning is that keen and able students as well as students who struggle, and all the students between the ends of these spectrum are supported in their individual development. This requires the practices of technology developers, teachers, and teacher educators to consider the characteristics, goals, and needs of school students. In our study, we contribute an evidence-based resource that should support these three target groups in rendering their practices user-centred.

Conclusions

The goal of this work is to support technology developers, teachers, and teacher educators in establishing TELEs that are geared to different characteristics, goals, and needs of students in Austrian academic upper secondary schools. The results of our study are presented as personas. In the context of developing TELEs or creating content for TELEs, personas provide an easy to grasp presentation of potential users.

Personas offer a relatable account of students' desires and needs for a TELE. In this way, personas could help ensure that the entire spectrum of student needs remains in sight when developing TELEs. Especially in mathematics, personas could be of particular importance when developing TELEs because mathematics is a subject that frequently evokes strong emotions, and diverging interests and strengths of students are particularly evident. This may also be true of other subjects. However, unlike many other subjects such as physics or arts, mathematics is a compulsory component in the school leaving exam of Austrian academic upper secondary schools, where it is taught throughout all grades. For this and other reasons, TELEs should be developed with particular care and consider the interests and needs of different types of mathematics students.

Limitations and future directions

The data we collected on the goals and needs of students are qualitative. The quantitative data in our study are of a general nature and were used to frame the target group; they did not capture the characteristics and needs of students directly. In a future study, quantitative data on the achievement goal orientation and self-determination of students could lead to a more comprehensive and precise picture of students' varying attitudes towards learning mathematics and their corresponding requirements on TELEs. The answers to the open-ended questions of our questionnaire did not address all manifestations of achievement goals and basic psychological needs. This could be remedied in a future quantitative study guided by the insights from the present qualitative study. Finally, it will be interesting to study how teachers make use of personas and how they assess their usability and benefits.

In contributing pedagogical knowledge to the design of TELEs, our work did not aim at identifying explicit features of technologies that certain groups of students require. Also, TELEs with a design that comprehensively considers pedagogical factors cannot go without the situational knowledge of teachers that is necessary for highly specific situations. Therefore, our work aimed to bridge the gap between expertise of developers and the professional knowledge of teachers for designing TELEs.

Abbreviations

TELE: technology-enhanced learning environment; UX: user experience.

Endnotes

[a] According to data retrieved from *STATcube*, the public database of Statistics Austria, in 2019 37,853 students in academic upper secondary schools in Austria ("AHS-Oberstufe" and "Oberstufenrealgymnasium") were from "densely populated areas" and 42,157 were from "intermediate density areas" or "thinly-populated areas". In the school year 2019/20, 14,509 out of 22,546 active teachers in academic secondary schools in Austria were female. In the school year 2016/17, 67% of the teachers in academic secondary schools were 40 years or older (Breit et al., 2019).

Authors' contributions

Conceptualization: R.W., M.M., Z.L.; methodology: R.W., M.M.; validation: R.W., M.M.; formal analysis: R.W., M.M.; investigation: R.W., M.M.; data curation: R.W., M.M.; writing—original draft preparation: R.W., M.M.; writing—review and editing, R.W., M.M., T.H., Z.L., M.E.; visualization: R.W., M.M.; supervision: Z.L., M.E., M.H.

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M.H. has created the open source dynamic mathematics software *GeoGebra* in 2002 as part of his master's project in Austria. After his PhD he spent three years at universities in Florida before he became a full professor for mathematics education at Johannes Kepler University Linz in Austria in 2010 where he is still leading the development of *GeoGebra*.

Funding

This research received no external funding.

Availability of data and materials

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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Received: 1 June 2022 Accepted: 28 November 2022
Published: 28 February 2023 (Online First: 2 January 2023)

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