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ORIGINAL PAPER

Cognitive appraisals as mediators of the relationship between digital technology use and students' achievement emotions in science and mathematics subjects

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Abstract
Based on the control-value theory, we investigated the achievement emotions experienced in science and mathematics classes by high school students in the context of digital technology use for educational purposes. Specifically, we examined the mediating role of cognitive appraisals of control and value in the relationship between students' digital technology use and emotions. Data were collected through online questionnaires from a sample of 1476 first- and second-grade high school students from 50 schools. The results of path analyses revealed that digital technology use (i.e. students' ICT-based activities related to learning) was positively associated with enjoyment and pride, both directly and indirectly through the perceived competence (control appraisal) and interest (value appraisal) in science and mathematics subjects. Findings further indicated that digital technology use was not directly negatively related to emotions of anxiety and boredom, but rather indirectly through students' cognitive appraisals. The perceived competence as control appraisal mediated the relation between digital technology use and both anxiety and boredom, while the perceived interest and importance as value appraisals mediated the effect of digital technology use on boredom only. The results can help educational practitioners to shape technology-based learning environments in affectively beneficial ways by utilizing learning technologies that enhance students' sense of competence and promote interest and value in mathematics and science subjects.

Keywords Achievement emotions · Control-value theory · Digital technology · Science · Mathematics

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Introduction

Technology-based learning (TBL) environments are becoming increasingly important in twenty-first century education for providing opportunities for a substantial transformation in students' learning processes compared with traditional instruction. However, transforming the learning experience through the integration of technology is a complex endeavour because these environments also challenge students to develop new learning habits and routines. In this context, researchers have recently focused their efforts on understanding and supporting emotional processes involved in TBL. Examining emotions within a TBL environment is crucial to determine how technology can effectively support adaptive emotions that foster cognitive and affective learning outcomes. Students' emotional experiences when learning with technologies have been investigated within diverse conceptual frameworks including theories of self-regulated learning (Gegenfurtner et al., 2021), interest theory (Hidi & Renninger, 2006), learning-centered emotions approaches (also referred to as epistemic emotions; D'Mello & Graesser, 2012; Muis et al., 2015), the cognitive-affective model of learning with media (Moreno & Mayer, 2007), and the control-value theory of achievement emotions (CVT; Pekrun, 2006, 2019).

As an integrative framework for analyzing the antecedents and effects of emotions experienced in academic settings, CVT posits that achievement emotions occur as a consequence of control and value appraisals (Pekrun, 2006, 2019). These appraisals are assumed to be shaped by, as well as to mediate the effects of, more distal individual and environmental antecedents of emotions. Recent literature reviews (e.g. Loderer et al., 2020) of research examining TBL environment as distal antecedent and its effects on appraisals and emotions support the generality of these functional mechanisms. Nevertheless, the empirical support for the mediating role of appraisals is relatively scarce in general (Goetz et al., 2020).

Employing CVT as the theoretical framework, the current study aimed to address this gap, and contribute to the ongoing discourse on the universality of theory for the TBL environment. Specifically, we investigated the achievement emotions experienced in science and mathematics classes by high school students in the context of digital technology use for educational purposes. We focused on students' engagement in diverse ICT-based activities related to learning, such as searching the internet for relevant content, online collaboration or using educational games/quizzes. Relationships between technology use and emotions, along with the mediating role of control and value appraisals, were contextualized within the national-level implementation of digital technologies in the Croatian educational system.

Theoretical framework

Achievement emotions in academic contexts include emotions related to achievement activities (e.g. learning) or achievement outcomes (e.g. success or failure) (Pekrun, 2019). Both pleasant and unpleasant emotions, which are ubiquitous in academic settings, play important roles in learning and performance processes, as well as in students' general well-being (Goetz et al., 2016). Moreover, Frenzel et al. (2007) noted that achievement emotions are also critical to students' academic success, because students are more willing to invest further effort in learning when they are affectively

rewarded for doing so. Emotional 'attraction' to a particular subject leads to a greater interest in learning and possibly the choice of a future career in that field. Because of the importance of achievement emotions in education, Mayer (2020) points out that many researchers emphasise the need to expand existing theories of academic learning by including affective processes as an essential component.

Achievement emotions are associated with student characteristics such as cognitive abilities, motivation, interest, values, attitudes, and personality traits. However, emotions occurring in the educational context are also shaped by various environmental and social aspects of teaching, such as quality dimensions of instruction (teacher enthusiasm), the degree of autonomy given to students, values and expectations of significant others, goal structures and classroom interaction structures, feedback and consequences of achievement, and social relatedness and support in academic interactions (Pekrun et al., 2002). In other words, characteristics of learning environment and teaching can be seen as antecedents of students' emotions (Goetz et al., 2016). Students' emotional experiences might also differ when using traditional teaching methods compared with teaching with digital technologies, which is increasingly common in contemporary education.

Loderer et al. (2020) believe that TBL strongly influences students' achievement emotions and that these academic emotions are best explained through the integrative framework provided by the control-value theory (CVT) of achievement emotions (Pekrun, 2006). The theory posits that individuals experience certain emotions when they feel that they have or do not have control over activities and achievement outcomes that they consider to be subjectively important. Two groups of appraisals are particularly important for achievement emotions: (1) subjective control over achievement activities and their outcomes; and (2) subjective value of those activities and outcomes (Pekrun, 2006). These appraisals are direct determinants of achievement emotions (Pekrun, 2019). Control appraisals are defined as perceptions of one's competence in performing actions and achieving favourable outcomes. Academic self-concept and self-efficacy are commonly used as indicators of control beliefs in the CVT (Goetz et al., 2020; Loderer et al., 2020). Value appraisals refer to the perceived importance of learning and achievement-related activities and outcomes. Typical variables used to capture value appraisals are intrinsic and extrinsic value or utility of task (Goetz et al., 2020; Loderer et al., 2020). From an educational perspective, such appraisals can be considered as potential mediators in the relationship between situational factors and achievement emotions and can be utilized in educational interventions to promote positive emotional development in students (Pekrun et al., 2002).

Emotions experienced in academic settings have been found to vary across different subject areas (Goetz et al., 2007). Learning science and mathematics subjects encourages students to think logically and critically and prepares them to participate consciously and actively in society. However, there is often a perception that science subjects are rational, cold, and methodical, which can trigger negative emotions in students even before they encounter the subject. Relations between emotions and academic achievement seem to be stronger in the mathematics and science domains as compared with verbal domains (Goetz & Hall, 2013).

Empirical research on emotions experienced in science subjects has mostly focused on anxiety and enjoyment (Sinatra et al., 2014). Meta-analyses consistently show significant negative relations between anxiety and achievement outcomes (Goetz & Hall, 2013; Zhang et al., 2019). High or increasing levels of mathematics anxiety during adolescence are likely to lead to avoidance STEM careers (Ahmed, 2018). On the contrary, research shows that students can enjoy learning science and become very interested in the field. Ainley

and Ainley (2011) found that students who rate science and mathematics subjects as more important to their lives enjoy the classroom more.

Current educational paradigms increasingly focus on students and their active participation in the teaching process, with the use of information and communication technology (ICT) in teaching being a means to achieve this. Learners have to be actively engaged with the material in order to comprehend new information, which is facilitated by the use of interactive digital learning environments that allow learners to actively and directly influence their own learning process. Digital technologies enable students to receive additional information and feedback, to control their individual pace of learning, manipulate presented information, seek and find new content material, and navigate through different content areas and therefore to actively construct meaning (Moreno & Mayer, 2007). Pekrun (2006) emphasizes the significance of learning environments that foster autonomy and cooperation, enabling students to self-regulate their learning processes. Such environments promote students' sense of competence, yielding a positive impact on their emotions.

Digital technologies have the potential to improve the teaching process in mathematics, physics, chemistry, and biology subjects when it comes to assessing content knowledge, as well as developing skills that are important for science subjects, such as inquiry-based learning (Deák et al., 2021). Because of their complex and often abstract nature, many concepts taught in STEM subjects are difficult to explain using traditional teaching methods, and their understanding often requires a high level of visualization, which can be achieved using digital technologies in learning and teaching. Extensive meta-analysis (Hillmayr et al., 2020) showed that secondary school students who were taught using digital tools in science or mathematics classes had significantly better learning outcomes and more positive attitudes toward the subject than students who were taught without the use of digital tools. Rončević Zubković et al. (2017) found that STEM teachers were more likely to report using digital technologies in lesson preparation and classroom activities, reported more benefits of ICT use in the classroom, and perceived themselves as more competent in the use of digital technologies compared with humanities and social sciences teachers.

Most research on the use of ICT in STEM subjects has been focused on mathematics education. Sinclair and Yerushalmy (2016) note that, in the context of mathematics teaching, there is an increase in the accessibility of technology that is becoming integrated in various practices of teaching, such as proposing problems and assessing student learning. They list several types of digital technology improvement and broadening. Evolution is evident in open digital technologies that do not contain mathematics-specific embedded tasks and are thus open to a wide range of potential actions and uses (Logo, Cabri, Sketchpad, CAS); task embedded digital technologies that contain embedded tasks, which direct the actions and uses to more specific purposes; and evaluative technologies that provide feedback on students' responses and actions.

As in mathematics, teachers are increasingly using ICT as a teaching tool in physics classes. ICT allows teachers to explain complex concepts more easily and proves useful in laboratory exercises and demonstrations of various phenomena or laws. Kola (2013) highlights the usefulness of computer programs in explaining various mechanical and electromagnetic principles, wave motion, radioactivity, and nuclear physics, especially in schools that do not have all the necessary instruments and tools for direct demonstration. Drigas and Kontopoulou (2016) studied the use of digital technologies in physics education at all educational levels, from elementary to higher education, and cited video simulations, virtual reality, and digital learning games as the most useful tools.

Pernaa and Aksela (2009) emphasize the importance of practical work through modelling in chemistry classes and note that this work can be further enriched by using ICT tools

in learning and teaching. Furthermore, the use of ICT in the laboratory not only facilitates work on experiments, but often provides additional safety while conducting them. The authors highlight the use of visualization methods, which include computer-based molecular modelling, simulations, animations, computer-assisted conceptual framework modelling and micro-computer-based laboratories. The results of their research show that ICT-supported practical work enhances the teaching and learning of difficult chemical concepts, stimulates interest in chemistry, and develops research skills.

Topics covered in biology classes, such as cellular processes, the functioning of organic systems, or photosynthesis, can be presented with computer animations, while content relevant to personal and social development, such as raising ecological awareness, can be addressed through various video and audio displays, and preferably using of virtual and augmented reality. For example, immersive virtual reality can be an effective educational medium to teach the consequences of climate change, especially ocean acidification, because it increases interest and knowledge through the immersive underwater world of the polluted ocean (Markowitz et al., 2018).

Generally, the use of digital technologies is expected to have positive effects on learning and teaching in various educational areas. The main advantages of digital technologies are faster access to information and easier visualization of scientific concepts and phenomena. They also enable students to conduct independent and collaborative research and actively participate in the educational process (Moreno & Mayer, 2007).

Given the importance of emotions in the learning process, which has received increasing attention in recent years, Mayer (2020) presented a cognitive-affective model of academic e-learning that focuses on the role of emotions in technology-enhanced learning. The model includes four components: (1) a learning episode interacting with technology (TBL or e-learning), (2) emotional response from the student, (3) cognitive processing that refers, for example, to a level of engagement and use of learning strategies, and (4) learning outcome.

Grounded in CVT of emotions (Pekrun, 2006), the systematic review and meta-analysis of Loderer et al. (2020), has helped to explain the relationship between these elements. Loderer et al. (2020) believe that the theory is universal enough to explain students' emotional functioning in a variety of learning contexts, including learning with technology. The authors also suggest that evidence-based principles for designing effective TBLs could be derived based on these findings.

As mentioned earlier, the main assumption of CVT is that individual differences among students and characteristics of the learning environment influence emotions by affecting students' perceptions of value and control. For example, students' experience with digital technology can influence their perception of control over a particular learning task, which in turn affects their emotions. Basically, the theory assumes that perceptions of high control and positive value of a learning task are associated with positive emotions, such as enjoyment of using the technology. On the other hand, negative perceptions of control and value of the task negatively affect emotions, leading to anxiety, for example. As for boredom, studies showed that it is often caused by a lack of value, because of either an insufficiently challenging activity (high-control/low-demands situations) or when activity demands exceed students' capabilities (low-control/high demand situations) (e.g. Camacho-Morles et al., 2019; Loderer et al., 2020). Thus, in demanding STEM subjects with a low level of control, a negative relation between control and boredom could be expected.

In general, two possible cognitive-affective pathways can be identified: a positive and a negative one (Mayer, 2020). A positive cognitive-affective pathway refers to a learning episode with high perceived control and value, leading to greater enjoyment and higher

levels of engagement in the task, and thus to better learning outcomes. On the other hand, a negative cognitive-affective pathway refers to a learning episode with low perceived control and value, leading to higher levels of anxiety, lower engagement, and poorer learning outcomes.

When examining the impact of digital technologies for learning purposes, Loderer et al. (2020) found that students who rated technology more positively enjoyed learning more, while the reverse relationship held true for anxiety. When comparing learning episodes with and without technology, TBL was found to have small but positive effects on enjoyment of learning and negative effects on anxiety, particularly in mathematics and science subjects. These two emotions are also the most researched in this context.

The present study

In Croatia, substantial efforts have been made to introduce digital technologies in the educational system with the purpose of creating digitally mature schools through the project e-Schools: Establishing a System for the Developing Digitally Mature Schools (Pilot Project), which was supported by the Croatian Academic and Research Network, CARNET. The project equipped participating schools with appropriate ICT infrastructure. Participating teachers were educated on the use of digital technologies and digital educational content. In science and mathematics classes, teachers were provided with teaching scenarios to stimulate ideas for conducting activities using contemporary pedagogical methods and digital tools (Mišurac, 2017). By creating innovative learning environments, the ultimate goal of the project was also to develop students' digital competencies and prepare students to pursue further education and thrive in the competitive job market.

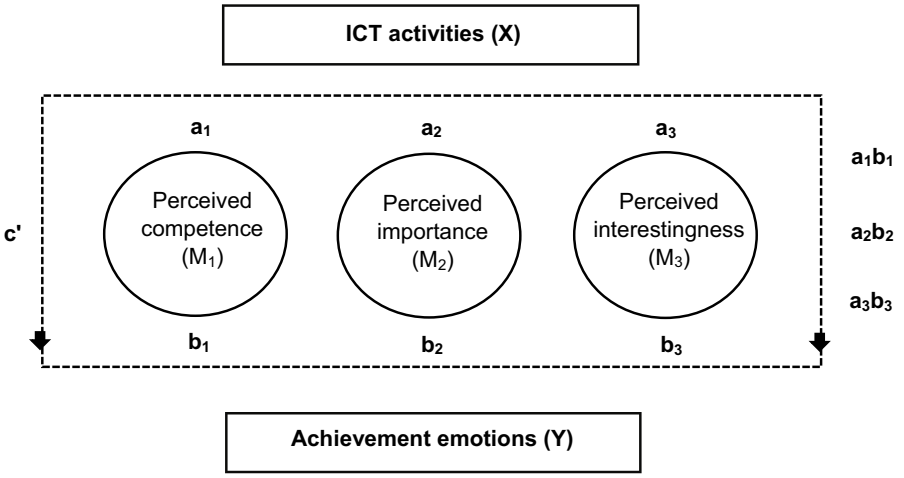
Situated within the abovementioned broader context, the current study addressed the applicability of CVT to TBL environments to contribute to ongoing discourse on the generality the functional mechanisms proposed by the theory. Although the hypothesis about the mediating role of control and value appraisals between learning environment and students' emotions is central to CVT, empirical support for that relationship is generally scarce (Goetz et al., 2020).

In order to address this gap, the present study investigated the experience of different achievement emotions in 1st and 2nd grade high school students in the context of using digital technologies for educational purposes. To this end, the potential direct effects of the frequency of ICT-based activities use on students' achievement emotions (boredom, enjoyment, anxiety, and pride), as well as the mediating role of students' value and control appraisals in the relationship between ICT-based activities and the experience of aforementioned emotions, were examined. The following primary hypotheses were examined (Fig. 1):

Hypothesis 1 (ICT activities → appraisals) ICT-based activities related to learning have a positive effect on students' perception of importance and interestingness (value) of science and mathematics subjects and competence (control) in these subjects.

Hypothesis 2 (ICT activities → emotions) ICT-based activities have a positive effect on students' experience of enjoyment and pride, and a negative effect on their experience of anxiety and boredom.

Hypothesis 3 (appraisals → emotions) Perceptions of control and value in science and mathematics subjects have a positive effect on student experience of enjoyment and pride, and a negative effect on their experience of anxiety and boredom.



Note. a_1, a_2, a_3 – effects of ICT activities (X) on students' appraisals (M_1, M_2, M_3); b_1, b_2, b_3 – effects of students' appraisals (M_1, M_2, M_3) on achievement emotions (Y); c' – direct effect of ICT activities on achievement emotions; a_1b_1, a_2b_2, a_3b_3 – indirect effects of ICT activities on achievement emotions.

Fig. 1 Model of mediation effect of students' appraisals on the relationship between ICT-based activities related to learning and achievement emotions

Hypothesis 4 (mediational role of appraisals) Students' perceptions of control and value in science and mathematics subjects mediate the effects of school environment (i.e. ICT-based activities) on students' achievement emotions.

Method

Participants and procedure

The data used in this study were collected through online questionnaires administered at the end of the school year within the evaluation study of the effects of the e-School pilot project. The schools were selected by CARNET to be representative of schools in Croatia based on the type of school (elementary versus high school), index of development, school size, self-report about technical equipment, and experience with ICT.

For this study, of the total student sample participating in the e-Schools pilot project (7th and 8th grade elementary school students and 1st and 2nd grade high school students), only high school student data were used. In each school, students from the targeted grades were randomly selected. The number of selected students was proportional of school size. A representative sample of 10% of high school students from 50 participating schools included 1476 students (n first grade = 760, n second grade = 716), of whom 45.1% were boys (n = 666) and 54.9% were girls (n = 810). The parents or guardians provided written informed consent for their children's participation in the study. At the beginning of the questionnaire administration, students were apprised in writing of the voluntary nature of their participation and assured of confidentiality. Personal data underwent conventional anonymization procedures and were securely stored. The students completed

the questionnaires within the school premises, during regular school hours, and under the supervision of school psychologist or pedagogue. Students took approximately half an hour to complete the questionnaires.

Instruments

ICT-based activities related to learning

The questionnaire (CPP, 2018) consisted of 8 items such as "I look for content to help me write homework, reports, or reading notes" that assess the frequency of various activities related to the students' use of digital technologies for school tasks and purposes. Students responded on a 4-point Likert scale (1—never, 2—several times a month, 3—several times a week, 4—daily). Analysis concerning the structural validity of the scale was conducted using confirmatory factor analysis (CFA) in *Mplus 8* (Muthén & Muthén, 2012–2017). The analysis was performed using a maximum likelihood (ML) estimation. Goodness of fit was evaluated using the comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). The following criteria were used to evaluate the adequacy of model fit: CFI/TLI ≥ 0.90 and ≥ 0.95 (Hu & Bentler, 1999), and RMSEA/SRMR ≤ 0.05 and ≤ 0.08 (Browne & Cudeck, 1992). The initial CFA revealed rather poor data fit, $\chi^2(20) = 424.74$, $p < 0.001$, CFI = 0.86, TLI = 0.80, RMSEA = 0.117 (90% CI [0.108, 0.127]) and SRMR = 0.063. Based on the modification indices, the model fit was further improved through correlating error-terms between three pairs of items and, consequently, the data showed an acceptable fit, $\chi^2(17) = 185.08$, $p < 0.001$, CFI = 0.94, TLI = 0.90, RMSEA = 0.082 (90% CI [0.071, 0.093]) and SRMR = 0.042. The internal consistency (Cronbach's alpha) of the questionnaire was 0.78.

Perception of importance, interestingness and competence in science and mathematics subjects

Students rated on a 7-point Likert scale how important and interesting they consider each of the four school subjects of mathematics, physics, chemistry, and biology (1—not at all important/interesting, 7—very important/interesting), and how competent they consider themselves in the mentioned subjects (1—I am not at all good in the subject, 7—I am very good in the subject) (Niemivirta, 2004). The internal consistency (Cronbach's alpha) of the Importance and Competence scales was 0.73, while for the Interestingness scale was 0.67.

Achievement emotion questionnaire

Students' experience of four emotions—enjoyment, pride, anxiety, and boredom—was explored in the context of teaching mathematics, physics, chemistry, and biology. Originally, the Achievement Emotions Questionnaire (AEQ, Pekrun et al., 2011) was an extensive instrument consisting of 24 scales, designed to assess various class-related, learning-related, and test-related emotions. The class-related portion originally included 80 items and requested students to indicate how they feel regarding class-related enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom (Pekrun et al., 2011). In the present study, we used 12 items of the AEQ, three items for each emotion. Students answered on a 5-point Likert scale (1—strongly disagree, 5—strongly agree). The results of confirmatory

factor analysis (CFA) for achievement emotions (i.e. enjoyment, pride, anxiety, and boredom) demonstrated acceptable model fit, $\chi^2(48) = 616.32$, $p < 0.001$, CFI = 0.91, TLI = 0.87, RMSEA = 0.090 (90% CI [0.083, 0.096]) and SRMR = 0.053, and the fit was further improved through correlating error-terms between one pair of items measuring enjoyment and pride, $\chi^2(47) = 397.56$, $p < 0.001$, CFI = 0.94, TLI = 0.92, RMSEA = 0.071 (90% CI [0.065, 0.078]) and SRMR = 0.047. The Cronbach alpha reliability coefficient for the Enjoyment scale was 0.70, for the Pride scale 0.72, for the Anxiety scale 0.59, and for the Boredom scale 0.83.

Results

Data analysis was performed using IBM SPSS Statistics v27. The Process macro 3.5.3 extension for SPSS was used to conduct the mediation analysis (Hayes, 2018). Table 1 shows correlations and descriptive data for the variables studied.

Enjoyment and pride were significantly positively related to students' perceptions of importance, interestingness, and competence in science and mathematics subjects, as well as to ICT-based activities. Anxiety was significantly positively related to ICT-based activities and negatively related to students' perceptions of importance, interestingness, and competence in science and mathematics subjects, but the correlation coefficients were very low. Boredom was significantly negatively related to the cognitive appraisals, while the correlation with the ICT-based activities was also negative, but very weak.

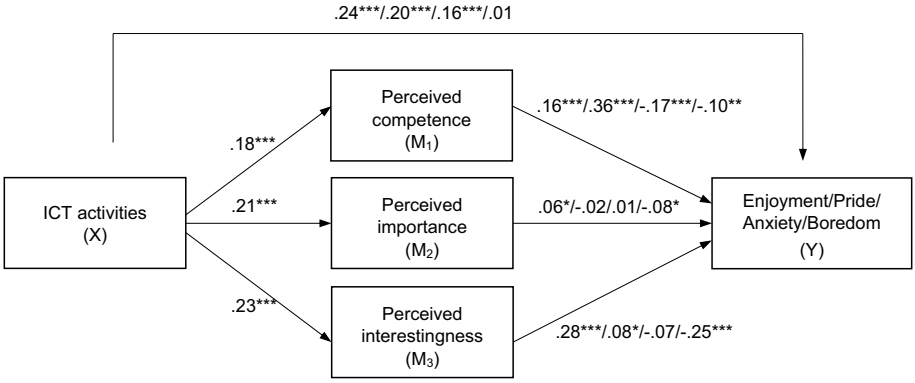
To examine the mediating role of students' appraisals of the importance of and interestingness in science and mathematics subjects, as well as their competence in these subjects, in the relationship between ICT-based activities related to learning and achievement emotions, four multiple mediation analyses were conducted with three parallel mediators.

Hypotheses were tested by regression analyses based on 5,000 bootstrapped samples using bias-corrected and accelerated 95% confidence intervals (CIs) with centered variables. Mediation (indirect effect) is considered significant if the upper and lower 95% CIs do

Table 1 Descriptive and Pearson correlations between ICT-based activities related to learning, cognitive appraisals and achievement emotions

Variable	Correlations							
	1	2	3	4	5	6	7	8
1. ICT activities	1							
2. Perceived importance	.17**	1						
3. Perceived interestingness	.20**	.68**	1					
4. Perceived competence	.19**	.51**	.59**	1				
5. Enjoyment	.35**	.30**	.38**	.33**	1			
6. Pride	.29**	.24**	.28**	.33**	.66**	1		
7. Anxiety	−.11**	−.11**	−.12**	−.18**	−.15**	−.11**	1	
8. Boredom	−.08**	−.26**	−.31**	−.26**	−.44**	−.30**	.38**	1
M	2.33	5.45	4.69	5.00	3.33	3.63	3.06	3.04
SD	0.53	1.08	1.25	1.11	0.77	0.73	0.93	1.03
Range	1–4	1–7	1–7	1–7	1–5	1–5	1–5	1–5

**$p < .01$



*$p < .05$. **$p < .01$. ***$p < .001$.

Fig. 2 Path analyses for the four achievement emotions

Table 2 Indirect effects of ICT-based activities on achievement emotions

Cognitive appraisal	Indirect effect via			Total indirect
	Importance	Interestingness	Competence	
Enjoyment	.013 [−.002, .028]	.065 [.042, .090]	.029 [.016, .044]	.106 [.080, .133]
Pride	−.003 [−.019, .011]	.018 [.000, .039]	.067 [.045, .090]	.082 [.056, .108]
Anxiety	−.003 [−.018, .012]	−.017 [−.037, .002]	−.031 [−.048, −.017]	−.050 [−.070, −.033]
Boredom	−.017 [−.033, −.003]	−.058 [−.082, −.037]	−.018 [−.032, −.006]	−.093 [−.118, −.071]

The 95% CIs are shown in square brackets

**$p < .01$

not contain zero (MacKinnon et al., 2004; Preacher & Hayes, 2008). The parameters presented in this paper are standardized. Following Kline's (1998) guidelines, values greater than 0.10, 0.30, and 0.50 generally reflect small, moderate, and large effect sizes. The direct effects of ICT-based activities related to learning on each of the achievement emotions as well as the mediation effects of the value and control appraisals (perceived importance of and interestingness and competence in science and mathematics subjects) were observed. The results are presented in Fig. 2 (direct effects) and in Table 2 (indirect effects).

Significant positive total effects of students' ICT-based activities on enjoyment ($\beta = 0.35$, $p < 0.01$), pride ($\beta = 0.29$, $p < 0.01$) and anxiety ($\beta = 0.11$, $p < 0.01$) were found, while the total effect on boredom was negative ($\beta = -0.08$, $p < 0.01$). As shown in Fig. 2, a significant direct effect of ICT-based activities on the emotions of enjoyment, pride, and anxiety was found, while the direct effect on boredom was not significant. ICT-based activities also showed statistically significant effects on all three cognitive appraisals (importance, interestingness, and competence in science and mathematics subjects). Perceived competence had a significant positive effect on enjoyment and pride and a negative effect on anxiety and boredom. Perceived importance had a significant but very small positive effect on enjoyment, and also a very small negative effect on boredom. Perceived interestingness had a significant positive effect on enjoyment and pride and a negative effect on boredom.

The indirect effect of ICT-based activities through perceived competence proved significant for all four emotions, while the indirect effect of ICT-based activities through interestingness was found to be statistically significant for the emotions of enjoyment, boredom, and, marginally, pride. Perceived importance proved to be a significant mediator only for the relationship between ICT-based activities and boredom. The obtained effects were weak.

Discussion

The school environment creates situations full of challenges, expectations, and demands in which students are expected to acquire knowledge, but also to demonstrate outcomes and ultimately to be assessed. As Niemivirta et al. (2019) stated, students' appraisals of the personal significance of such situations and their own resources to cope with them determine students' emotions and readiness to act. The control and value theory of achievement emotions (Pekrun, 2006) was used as a framework to explain the emotions thus elicited in the school setting.

In the present study, we examined the proposed role of control and value appraisals in science and mathematics subjects in explaining students' emotions of enjoyment, pride, anxiety, and boredom. Loderer et al. (2020) assert that CVT can serve as a framework for studying emotions in different academic domains and various learning settings, including technology-enhanced learning. Therefore, students' engagement in ICT-based activities related to learning were also considered in this study, representing an e-learning episode or a setting that, according to the cognitive-affective model of e-learning (Mayer, 2020), shapes emotional reactions of students.

Mediation models have been tested that postulate that cognitive appraisals of value (importance and interestingness) of science and mathematics subjects, as well as control (perceived competence) in these subjects, mediate the relationship between students' use of digital technologies for school tasks and achievement emotions. A direct effect of the frequency of ICT-based activities on emotions was also hypothesised.

Although it was assumed that ICT-based activities related to learning would have a significant positive effect on experiencing enjoyment and pride, and a negative effect on experiencing boredom and anxiety, the obtained results confirmed these hypotheses only partially. While ICT-based activities indeed led to more joy and pride among students, the direct effect of ICT-based activities on boredom was not observed, while the direct effect on anxiety was positive, contrary to the original hypothesis.

The total indirect effects of ICT-based activities related to learning on achievement emotions through cognitive appraisals were found to be significant, confirming the hypothesis that appraisals of control and value of STEM subjects mediate the effects of ICT-based activities on achievement emotions. However, while students' perceived competence was a significant mediator between the frequency of ICT-based activities and all the achievement emotions studied, that was not the case for value indicators.

The finding that perceived competence was the significant mediator is consistent with the assumption that perceived control can mediate the effects of the learning environment on students' achievement emotions (Camacho-Morles et al., 2019; Loderer et al., 2020; Raccanello et al., 2022). Loderer et al. (2020) state that perceptions of higher task clarity and structure and ease of use of a digital tool increase students' sense of control. The authors note that, in this way, it is possible to promote positive emotions and reduce

negative ones by providing cognitive and metacognitive support to promote the learning process. Teachers in Croatia have been found to use technology primarily for content presentation and for collecting and publishing of student work while, to a lesser extent, they encourage students to engage in student-centered activities (Mohorić et al., 2020). Mayer (2020) emphasizes the importance of emotional design, which refers to the design of learning episodes using digital technology that triggers emotions that enable deep cognitive processing and lead to higher-order learning outcomes.

The present study shows that students who used digital technologies more frequently considered themselves more competent in science and mathematics subjects and consequently felt more enjoyment and pride, and less boredom and anxiety. The strongest mediation effect of competence was found for feelings of pride. This is not surprising, because pride is considered a control-dependent retrospective outcome emotion triggered by attributing success to oneself (i.e. ability and effort) (Pekrun, 2006). Along with hope, pride was found to have the highest correlation with self-efficacy (Pekrun et al., 2011).

According to CVT (Pekrun, 2006), the perceived positive value, indicated here by the importance and interestingness of the subject, should trigger positive emotions, while the opposite is true for the perceived negative value that should induce negative emotions. However, the results of the present study do not fully confirm the hypothesized relationships. The interestingness of the subject proved to be a significant mediator of the relationship between frequency of ICT-based activities and enjoyment, boredom, and marginally pride, whereas the mediation effect for anxiety was not significant. Previous studies have shown that interest in learning was most strongly related to enjoyment and boredom (Pekrun et al., 2002), which was also evident in our study. It appears that the use of digital technologies might foster the perception of STEM subjects as interesting, which in turn reduces boredom and increases enjoyment. Such interest, which is triggered by environmental stimuli, can be referred to as situational interest (Hidi & Renninger, 2006).

In addition to perceived interestingness, we expected that the perception of the importance of the subject would have a mediating effect between ICT-based activities related to learning and achievement emotions, but this was not confirmed, except in the case of boredom. In describing their four-phase model of interest development, Hidi and Renninger (2006) state that triggered situational interest, if sustained, can grow into a well-developed individual interest through the deepening of knowledge and values. Our results indicate that digital technologies exert their effects on emotions mainly through triggering interest but not through increasing the importance of science and mathematics subjects. Renninger and Hidi (2022) argue that making self-related connections to the content is crucial to trigger and sustain students' interest, which in turn offers opportunities for exploration, practice, and the development of conceptual understanding.

The results of our study, as well as the findings of Goetz et al. (2020), suggest that it is important to consider different aspects and indications of value appraisals when examining its mediating effects between educational settings and achievement emotions. Estimating models with multiple mediators allows us to compare the size of indirect effects through different mediators (Hayes & Rockwood, 2016). The results of the present study showed that, although both the importance and interestingness of STEM subjects were significantly related to ICT-based activities and achievement emotions, subject interestingness mediated the effect of ICT-based activities and the examined achievement emotions, except anxiety, while importance was a significant mediator only for boredom, although the effect was weak.

The finding that both importance and interestingness of the subject mediate the effects of ICT-based activities on boredom is in line with previous research suggesting that value

is particularly important for the emotion of boredom (Camacho-Morles et al., 2019; Pekrun et al., 2010). Sabourin and Lester (2014) found that boredom and other negative emotions can be associated with decreased motivation for students to use ICT, which is why they engage in other behaviors such as playing computer games instead of completing schoolwork. Hence, using ICT in the classroom alone is not enough to provide students with a more engaging and better learning experience, and to ensure that students are not bored in class. Because boredom was found to be the most persistent emotion, least likely to transition to another emotion and the only emotion consistently related to maladaptive behaviours (Baker et al., 2010), it is important to focus on increasing interest in the subject in order to decrease boredom in students. The use of digital technologies has been shown to be positively related to interest in the subject. Thus, it is important to harness the potential of digital technology to increase student interest. The term emotional design is used to describe the use of design features that aim to influence student emotions to enhance learning. Some of these design features relate to the way in which information is presented and others to the way in which interactions in the environment are structured (Plass & Kaplan, 2016).

Regarding anxiety, the result of our study that higher control is related to lower anxiety is consistent with previous findings showing that the perception of control is particularly important for experienced anxiety (Loderer et al., 2020). Anxiety is thought to be more complex than the more unidimensional emotions such as boredom and enjoyment and thus its relationship with cognitive appraisals could be more complex (Goetz et al., 2020). The effect of value appraisals on anxiety is likely to depend on perceived control. When value is high and control is present, anxiety is not experienced, whereas high values combined with low control lead to anxiety. Therefore, it would be useful to test the interaction effect of value and control appraisals on anxiety in future studies.

A review of research (Loderer et al., 2020) indicates that technology-assisted learning does not usually lead to heightened anxiety compared with traditional learning settings. The study on university students also showed that the use of mobile devices for academic purposes does not lead to technostress, but promotes academic performance (Qi, 2019). However, the direct positive effect of ICT-based activities on anxiety found in the present study suggests that using digital technology for school purposes can cause more anxiety in students. This finding is inconsistent with previous findings and could indicate that certain technical difficulties while using technologies could reduce the benefits of such instructional practices. Because our indicator of perceived control was competency in the subject rather than competency in the use of the technology, it is possible that the use of digital tools with which students were unfamiliar triggered anxiety. Although digital technologies have the potential to support students in self-directed learning, it has often been reported that some students lack competence in using digital technologies for educational purposes despite being considered digitally competent to use technologies for other purposes (Morris & Rohs, 2021). During the transition to new educational practices that incorporate technologies, some students might feel like ‘guinea pigs’, which makes them anxious (Parsons & Adhikari, 2016). Learning environments that are excessively challenging or foster unfavourable social comparisons could lead to adverse control appraisals and consequently, give rise to negative emotions such as anxiety (Pekrun, 2006).

However, increased levels of anxiety do not necessarily mean that performance suffers. In examining anxiety and self-efficacy in ICT use in a sample of students, Porto Bellini et al. (2016) found that high levels of anxiety and low levels of self-efficacy were barriers to the successful use of ICT for academic purposes. On the other hand, they also found that an overestimation of self-efficacy can indicate an unrealistic confidence in the use of

technology, and that a too-low level of anxiety could indicate that the student is not sufficiently engaged in the task. The authors believe that moderate levels of anxiety indicate that the student is taking the task seriously and trying to do his or her best.

Limitations and directions for future research

When considering the findings of the present study, several limitations have to be considered. The AEQ scales used were shortened and showed somewhat lower reliability, especially the anxiety scale. Therefore, the findings regarding anxiety should be interpreted with caution. The use of alternative statements that would result in greater homogeneity should be considered in future studies. Additionally, regarding limitations pertaining to measurement instruments, it should be noted that, because the concepts of interestingness, importance, and competence were measured with one statement per subject, and it would certainly be more advisable to use measures of perceived value that are more comprehensive and validated previously. In addition, because taking the average score for four subjects could result in unjustified averaging, future research should be limited to specific subjects and e-learning episodes. Furthermore, we explored reported ICT-based activities related to learning in general. Thus, future studies should focus on the effects of specific digital tools on cognitive appraisals and academic emotions, especially because recent meta-analyses (Higgins et al., 2017; Hillmayr et al., 2020) showed that different contextual factors within TBL environment can have differently-sized impacts on students' learning outcomes in mathematics and science subjects. Finally, given that this was a correlational study, we cannot infer causal relationships between variables. For drawing causal conclusions, experimental research should be conducted, and the effects of technology use on cognitive appraisals and academic emotions should be longitudinally monitored. Overall, because of the highlighted methodological limitations, the findings obtained in this study are tentative and deserve further exploration.

Contribution of the study and practical implications

Despite the limitations of the study, the obtained findings point to the importance of studying emotions in an academic context and suggest that CVT (Pekrun, 2006, 2019) has proven to be applicable in the context of TBL environments, in line with previous findings (Loderer et al., 2020). The results revealed that control and value appraisals played a prominent role in mediating the relationship between students' digital technology use and achievement emotions, confirming the functional mechanisms pertaining to antecedents and emotions as proposed by CVT (Pekrun, 2006, 2019) and cognitive-affective model of e-learning (Meyer, 2020).

The results of the present study indicate that digital technologies exert their effect on the emotions of enjoyment, pride, and boredom through interestingness of the subject. Therefore, digital technologies should provide opportunities for student-centred teaching that encourages students to make self-related connections that can foster deepening interest through sustained engagement and information seeking. By maintaining interest and increasing the value of the subject, digital technologies have the potential to reduce boredom and increase students' enjoyment and even pride. Likewise, the current study indicates a mediating effect of students' competence in mathematics and science subjects in the relation between digital learning technologies and all the examined academic emotions. Consequently, promoting environments that encourage the utilization of learning technologies

that enhance students' sense of control and competence in mathematics and science subjects is recommended.

Because science and mathematics subjects very often have the reputation of being difficult, boring, or even incomprehensible, the emotions that students experience during class are of great importance. These are subjects that form the basis for the continued pursuit of some of the most sought-after and lacking professions in the job market. A systematic investment in the quality of instruction and the development of student interest in science subjects would be beneficial, and this can be achieved by fostering enjoyable emotional learning experiences that enable students to feel competent.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethics approval and consent The study was conducted in accordance with the ethical standards of University of Rijeka and approved by Ethical Committee for Scientific Research of the Faculty of Humanities and Social Sciences University of Rijeka. The informed consent was obtained from parents/guardians and students were informed that participation was voluntary. All the authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and gave consent for submission and subsequent publication of the manuscript.

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