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EFFECTS OF A TRANSDISCIPLINARY EDUCATIONAL APPROACH ON STUDENTS' TECHNOLOGICAL LITERACY

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Abstract. *Technological progress, globalization and demographic changes have brought about transformations that have increased economic and social inequalities. A structural transformation in education could support economic growth and sustainability and could also be associated with common actions in science, technology, engineering and mathematics, together with social sciences, to mitigate the impact of these megatrends on inequalities. This research explores the effects of a technologically conceptualized transdisciplinary educational approach. A sample of 242 lower secondary school students was selected and a pre- and post-test research design was used to ascertain whether a two-level transdisciplinary educational approach used by technology teachers affected the development of students' technological literacy (TL). The task design included several real-life technological contexts and concepts wherein knowledge of other disciplines was needed to solve problems, create new knowledge and acquire higher-order skills while developing positive attitudes towards sustainable technology. A two-way analysis of variance indicated several significant effects of transdisciplinary education on the development of students' TL. These findings provide valuable insights into the nature of TL acquisition as a basis for curriculum design and the implementation of transdisciplinary technology education in the lower secondary school.*

Keywords: *technology education, transdisciplinary educational approach, real-life problems, technological literacy.*

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Introduction

Rapid changes in our social, economic, political, physical and digital environments demand a transformation in teaching and learning techniques to meet the sustainability needs of contemporary society. These megatrends are constantly transforming the way we act and interact in society and business, and the consumption of goods and resources. Science and technology education is not exempt here because technological development increases the gap between market needs and the outcomes of the entire education system from elementary school through to tertiary education. Meanwhile, the Organisation for Economic Co-operation and Development (OECD) reported that skills-based technological progress may increase inequalities in the labour market, where a highly skilled labour force is in great demand (OECD, 2019). Consequently, the general public's level of knowledge in science and technology appears to be low, which could affect informed decision-making on scientific and technological issues in a socio-economic context for the sustainable environment of society (Pleasants et al., 2019). The dynamic nature of these changes requires swift and decisive action in terms of educational policy aimed at inclusive and sustainable growth, wherein strong labour force performance is crucial for meeting the competitiveness goals of the national economy (OECD, 2019).

The contexts and concepts of technology education have changed in recent decades, and systematically evolved from a focus on skills to a focus on technological literacy (TL) (Doyle et al., 2018; Rossouw et al., 2011). The International Technology Education Association (ITEA) defined TL as "an individual's ability to use, manage, assess and understand technology" (ITEA, 2007, p.7). This literacy comprises practical knowledge, higher-order thinking skills (e.g., critical thinking, decision-making, and problem-solving), and positive attitudes towards technology on the cognitive, affective and conative subscales (Rossouw et al., 2011). It indicates a shift to more general technology education, as well as a trend towards the integration of several disciplines such as science, technology, engineering, and mathematics, the so-called STEM disciplines (Cencelj et al., 2019).

An effective technology education should focus on real-life problems, transcend and integrate disciplinary paradigms, include practices from differ-

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ent disciplines and society, and search for knowledge beyond disciplines (Aneas, 2015; Hirsch Hadorn et al., 2008). Moreover, Pohl and Hirsch Hadorn (2007) have provided a wide concept of transdisciplinary approach which "can: a) grasp the complexity of problems, b) take into account the diversity of life-world and scientific perceptions of problems, c) link abstract and case specific knowledge, and d) constitute knowledge and practices that promote what is perceived to be the common good" (Hirsch Hadorn et al., 2008, p. 30). Transdisciplinarity refers to common actions of "different academic disciplines working jointly with practitioners to solve a real-world problem" (Klein et. al., 2001, p.4). It can be effective in many disciplines (Hirsch Hadorn et al., 2008). Meanwhile, transdisciplinarity favours a transformative learning process that enhances the creation of new knowledge while acquiring the necessary psychomotor and interpersonal skills and attitudes in relation to technological issues in order to support the development of a sustainable natural, social and economic environment (Norden, 2018).

Transdisciplinarity can be used as an educational or/and research strategy in technology education from primary school to university courses (Aneas, 2015). Hirsh Hadorn et al. (2008) have stated that transdisciplinary approach relates to systems knowledge (current status), target knowledge (need for change) and transformation knowledge (transition). This mutual learning among different stakeholders might develop epistemically new insights for adequate decision-making and demand action-taking (Norden, 2018). Moreover, Park and Son (2010) have presented transdisciplinary educational approach, which focuses on the outcomes of interdisciplinary learning. Students work "jointly using shared conceptual framework that draws together concepts, theorise, and approaches from the parent disciplines" (Rosenfield, 1992, p. 1351). "It particularly emphasises students' learning experience in sharing their skills and experiences (cross-training) and producing new knowledge" (Park & Son, 2010, p. 3).

A significant shift towards contemporary transdisciplinary technology education was signalled by the development of the Standards for Technological Literacy (STL) in the USA (ITEA, 2007). These standards include numerous engineering and technical contexts and concepts, which can be divided into five categories: nature of technology, engineering and society, design, skills for a technological world society and the design world. The STL benchmarks have been developed to enable the measurement of TL as the main learning outcome, but some benchmarks are too broad, while others are too narrow, presenting difficulties in delivering content. STL-based technology education may be a means of integrating competences students have acquired in other subjects by reinforcing and complementing the knowledge obtained in other disciplines or subject areas (ITEA, 2007).

Some recent studies in countries where the national technology education curriculum is not aligned to the STL have revealed a low level of TL (Avsec & Jamšek, 2018; Avsec & Sczewczyk-Zakrzewska, 2017) when measured using holistic methods enabling the measurement of both technological knowledge and skills. Higher-order thinking skills are a critical category that indicates how well the technology education curriculum is developed. Informed decision-making regarding social, scientific and technological issues has become increasingly important in everyday life and work where people are faced with increasingly unpredictable and complex situations due to the rise of digital technologies.

Theoretical Background

Technology education students learn through practical teaching methods wherein their procedural and tacit knowledge is developed together with the psychomotor skills needed for the manipulation of tools and materials in a direct-manipulation learning environment (Reinsfield & Williams, 2018). Traditionally, the curriculum of elementary technology education covers three areas: technological knowledge, technological practice and the nature of technology (Rossouw et al., 2011). Kwon (2017) highlighted two methods for successfully delivering elementary school design and technology subject matter; design and problem-based learning. Moreover, students' practical work in design and technology is aimed at enhancing social interactions and teamwork, and learning outcomes are not connected with contemporary TL development (Doyle et al., 2019; Kwon, 2017).

In an attempt to bridge the gap between abstract conceptualization and applicability in various contexts as a phase in transdisciplinary approach, Rossouw et al. (2011) undertook an extensive Delphi study identifying the main concepts used in curriculum development, including (1) design, (2) systems, (3) modelling, (4) social interaction, (5) optimization, and (6) innovative learning. The concepts that were identified are context independent, suggesting wide applicability of concepts that are aimed at transdisciplinary teaching and learning (Doyle et al., 2018; Kwon, 2017; Norden, 2018; Rossouw et al., 2011), which may produce better results at higher cognitive levels (Slavinec et al., 2019). Rossouw et al. (2011) also proposed that the STL contexts should be elaborated as two-tier contexts after considering both one's real-life practice and the global dimension.

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These contexts might be useful for transdisciplinary teaching and learning where different methods can be used, for example, meaningful learning, problem-solving, team learning, design thinking, inquiry- and project-based learning, collaborative learning, hands-on activities, and appreciative inquiry wherein the levels of integration and cooperation differ (Stock & Burton, 2011). In particular, problem-based learning was seen as a positive approach to enhancing innovation capacity by providing the foundation for a STEM-capable labour force in the 21st century (Bartholomew & Strimel, 2018). Authentic real-life, open-ended problems connected with design as an activity support integrated learning while developing the cognitive competences necessary to enhance sustainability (Bartholomew & Strimel, 2018). The integration and exploration of different methods in various contexts might enhance students' TL, especially when transdisciplinary teaching is used to create the new knowledge needed for coping with the challenges presented by today's increasingly technological world (Norden 2018; Slavinec et al., 2019). A transdisciplinary approach to technology education may provide new synergies and complementary pedagogical qualities related to the sustainable development of society (Norden, 2018). The use of a transdisciplinary approach in delivering technology education might improve students' self-directed learning (Bartholomew & Strimel, 2018). While working in teams, students must be sufficiently competent in all STEM disciplines to combine various perspectives and build new conceptual frameworks (Norden, 2018; Stock & Burton, 2011). In responding to real-life problems, students draw on various types of knowledge while avoiding the exclusion of other types of knowledge that are not directly related to the issue (Stock & Burton, 2011). Transdisciplinarity involves active learning wherein the participation of every student is necessary to create new contexts or concepts (Stock & Burton, 2011) relating to the development of TL (Rossouw et al., 2015).

Technological Literacy

Technological literacy presents the main learning outcome of technology education (Avsec & Jamšek, 2018). It consists of three interrelated dimensions: a) technological knowledge (TK), b) technological capacity (TC), and c) critical thinking and decision-making (CTDM) (Avsec & Jamšek, 2016; ITEA, 2007). TK is factual and conceptual and is related to the contexts and rules that interconnect the facts and concepts (Garmire & Pearson, 2006, Luckay & Collier-Reed, 2014). TC is related to how well a person is able to use technology, and is reflected in cognitive skills, for example, logical thinking, divergent and convergent thinking, psychomotor skills, which involve manual dexterity and the use of methods, materials, tools, machines and devices, and interpersonal skills, for example, collaboration, cooperation, communication, and team learning, wherein a learner can apply their acquired knowledge to both solving and seeking out problems (Garmire & Pearson, 2006, Luckay & Collier-Reed, 2014). CTDM uses the knowledge, cognitive skills and personal, social and/or methodological skills acquired through learning to increase the probability of desired outcomes (Halpern, 2014). Critical thinking also enhances humans' visualization ability in the process of mentally constructing, shaping and understanding information to facilitate problem-solving in relation to technological issues contextualised transdisciplinary (Avsec & Ferk Savec, 2019; Luckay & Collier-Reed, 2014). Pleasents et al. (2019) argued that informed decision-making regarding societal and personal issues requires TL, but this has received insufficient attention in STEM education because learning standards tend to be monodisciplinary.

The aforementioned dimensions of TL can be effectively enhanced through integration in the STEM context, and thus can benefit the national economy by bridging the gap between market needs and the performance of the labour force (Tseng et al., 2013). A labour force that is equipped with STEM skills is considered extremely important in light of the fourth industrial revolution (Mohtar et al., 2019). Understanding the definition of technology as a process, by which man changes the natural environment to meet the needs and desires of society (Ardies et al., 2015), is crucial in relation to increasing interest in STEM. Students are able to develop positive attitudes towards STEM as a result of the contribution of STEM to social, economy and the physical environment (Tseng et al., 2013). Greater understanding of the benefits of technology and improved perceptions of future career opportunities enable students to better use their self-efficacy to improve their performance in STEM learning (Mohtar et al., 2019). Thus, attitudes towards technology may determine the level of a student's TL (Gu, Xu, & Hong, 2019).

To understand students' attitudes towards technology and whether they are cognitive (opinions, beliefs), affective (emotions, feelings) or conative (behaviours, inclinations towards action), a crucial factor is their understanding of technology (Ankiewicz, 2018; Ardies et al., 2015). In general, students have positive attitudes towards technology, but their limited understanding of technology requires rethinking (Ankiewicz, 2018). Some

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studies have found a correlation between students' attitudes and TK (Garmire & Pearson, 2006) based on the dimensions of TL defined by the ITEA (Rupnik & Avsec, 2019), but these studies are scarce, and the issue requires further investigation. Students' attitudes towards STEM seem to be stable, with good predictive strength across gender and grade levels. Some differences have been found, but they were regarded as insignificant (Zhou et al., 2019). Studies on students' attitudes towards technology revealed several influencing factors including gender, teachers, peers and parents, the home technological environment, and previous learning experiences and habits (Ardies et al., 2015; Mohtar et al., 2019).

The research pursued two main objectives: (1) understanding students' attitudes to technology through traditional teaching versus transdisciplinary teaching using a two-level task variation, and (2) exploring whether the transdisciplinary educational approach of the subject matter in relation to the level of difficulty of the technology (DT) improves the students' TL.

Thus, this research aimed to provide evidence of how transdisciplinary teaching improves TL development. The research was guided by the following research questions:

1. What are the differences in eighth-grade students' attitudes towards technology based on the educational approaches used to deliver technology education?
2. What are the effects of transdisciplinary technology education on eighth-graders' TL?
3. How does students' stimulating environment affect their acquiring of TL?

The research was conducted over the entire 2017/18 school year in lower secondary schools in Slovenia.

Research Methodology

Research Context

The TL of students commencing grade 8 in Slovenia has not changed over the last ten years (Avsec & Jamšek, 2018). It seems that the new design and technology curriculum that was introduced in 2011 has not increased students' TL, but merely maintained the status quo. In order to increase the level of students' TL, a transdisciplinary educational approach was designed and implemented in Slovenian lower secondary schools agreed with University of Ljubljana. This approach focused on the subject of design and technology in grade 8.

Design and technology subject matter. In Slovenia, the design and technology curriculum in grade 8 comprises seven interconnected content areas: design and work organization, technical and technological documentation, metals and engineering, technical assets, economics, computer aided design and manufacturing, and traffic education. The vast majority of curriculum benchmarks are positioned in the first three levels of Bloom's revised taxonomy: Knowledge (with the consequence of remembering), understanding and application (Krathwohl, 2002), while higher-level thinking in terms of design and technology is rarely required. The total allotted time in grade 8 is 35 periods (one period = 45 minutes).

Research design. Two experimental groups were selected, and transdisciplinary approach was delivered at either level 1 (low level) or level 2 (high level). The control group consisted of students subjected to traditional education. This is a teacher-centred approach where a teacher gives direct instructions and students learn through listening and observation where different learning materials are used such as textbooks, worksheets, digital presentations and handouts. A subject matter is rather monodisciplinary with a little connection between topics, while students acquire objective information of the learning content.

Experimental groups. Students participated in active learning and acquisition of knowledge and skills. Problems for transdisciplinary education arouse from particular knowledge requirements in the real-world. Cases, where knowledge is uncertain, were carefully selected as common problems in society and in the natural environment. A set of worksheets was designed on two levels for each subject content area (see Appendix A and B). A high degree of learning interactivity was achieved through the participatory framework of the students to solve problems. Students through different interactions, e.g., peer-to-peer, on-line, off-line, voice call, messaging, (1) grasped the complexity of the problem, (2) created a concept map of real-world diversity and current knowledge fusion, (3) linked their current knowledge about specific cases and their abstract creations or embodiments, and (4) created new knowledge which reflects aspects from several disciplines involved in the case solving and it reflects most desirable solution for all involved stakeholders. Students embed the case into social and scientific contexts and

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communicated solution against the teacher, parents or others affected. The next day in school, students reported their reflections and the realisation of the expected outcome with possible advancements.

The problem-solving context motivates students to think holistically, rather than in monodisciplinary terms. The types of student involvement and the degree of student engagement in learning are carefully designed based on common learning objectives and issues, with the teacher being an interactive learning designer.

Teaching in transdisciplinary approach was delivered through a two-level model. Level 1 comprises tasks at the first three levels of Bloom's taxonomy related to conceptual and procedural knowledge (see Appendix A). Level 2 comprises tasks at higher cognitive levels such as analysing, evaluating and creating, which are related to conceptual, procedural and metacognitive knowledge (see Appendix B). TCDM was emphasized using a problem-solving and -seeking process to find unique solutions to existing problems or new needs that were technological in nature. Task variation and students' divergent thinking support both the affective and psychomotor domains.

The traditional approach to the design and technology course is teacher-centred education combined with practical hands-on laboratory work. With a curriculum defined content areas were delivered traditionally using textbooks, lectures and digital presentations, while students' learning is focused on memorization of facts and objective information, with conceptual knowledge limited to the first three levels of Bloom's taxonomy. Students participate in laboratory work mainly to develop and master psychomotor skills. Interactions are subject driven, wherein the student is a knowledge receiver, while the teacher is a knowledge deliverer.

Sample

The research was conducted in five lower secondary schools in municipalities of different sizes in a range of urban and rural areas in Slovenia. These schools were selected as the average ranged schools available in report of National Examinations Centre in Ljubljana (Državni izpitni center, 2017). The sample was divided into three groups: a level 1 experimental group (65 students; 30 girls, 35 boys), a level 2 experimental group (94 students; 46 girls, 48 boys), and a control group (83 students; 46 girls, 37 boys). There was an almost even gender distribution (122 girls (50.4%) and 120 boys (49.6%)). At the beginning of the research, students were aged between 12 and 13 years as it is shown in Table 1.

Table 1
Sample statistics for technology education variables

Variable	Category	Frequency (n)	Frequency (%)
Gender	Boys	120	49.6
	Girls	122	50.4
Grade	8th	242	100
Diploma Father	ISCED ≥ 5	83	34.3
	ISCED < 5	159	65.7
Diploma Mother	ISCED ≥ 5	52	21.5
	ISCED < 5	190	78.5
Father's profession in connection with technology	Not at all	31	12.8
	A little	25	10.3
	Some	60	24.8
	Much	67	27.7
	Very much	59	24.4
Mother's profession in connection with technology	Not at all	90	37.2
	A little	71	29.3
	Some	47	19.4
	Much	22	9.1
	Very much	12	5.0
Technological toys and education sets	Yes	195	80.6
	No	47	19.4

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Variable	Category	Frequency (n)	Frequency (%)
Home technical workshop	Yes	121	50.0
	No	121	50.0
Advanced use of computer	Yes	72	29.8
	No	170	70.2
Siblings in technical professions	Yes	34	18.9
	No	146	81.1
Out-of-school technical activity	Yes	41	16.9
	No	201	83.1
Home technology Education preparation time per week	0 hours	86	35.5
	Less than 2 hours	135	55.8
	2-4 hours	19	7.9
	More than 4 hours	2	0.8
Elective technology education subject	Yes	89	36.8
	No	153	63.2
Further education	General upper secondary school	98	40.5
	High (technical) school	51	21.1
	Vocational school	93	38.4

Instrumentation

Given the multifaceted nature of technology education outcomes, various holistic measurement methods have been proposed (Avsec & Jamšek, 2016; Avsec & Jamšek, 2018; Kelley & Wicklein 2009; Rohaan et al., 2012; Gu et al., 2019).

The instrument for measuring technological literacy (MMTL) was used to determine the impact of technology education using different educational approaches to estimate a student's level of TL. This instrument was developed by Avsec and Jamšek (2016) and it is multi-dimensional in nature and can be used either in its entirety or by selecting the desired subscales. The MMTL encompasses three main dimensions of TL – TK, TC, and CTDM. It is centred on the STL issued by ITEA (2007). The STL in greater extent enable transdisciplinarity in educational settings (Rossouw et al., 2010).

The psychometric properties of the MMTL have been reported in several studies (Avsec & Jamšek, 2016; Avsec & Jamšek, 2018; Gu et al., 2019). Based on TL benchmarks, a test bank with 258 items was created, which are aligned with the three dimensions of the TL and cover the entire STL. For the purpose of this research, the TL test was generated, which consists of 35 multiple choice items. The test consisted of 11 items relating to TK, 12 items relating to TC and 12 items relating to CTDM. Students were given a choice of four responses for TK items and five responses for TC and CTDM items. For CTDM, the students' reasoning ability was measured for some items and they were given five justifications from which to choose (two-tier items) (Avsec & Jamšek, 2018). The performance of students at MMTL was used as a measure of TL. The maximum possible score was 35 points.

The students' attitudes towards technology were surveyed using a modified 25-item test of Pupils' Attitude toward Technology (Ardies et al., 2015). The survey questionnaire, which was titled *Technology and Me*, consisted of two groups of items. The first group focused on the stimulating environment of the student while the second group included items on students' attitude towards technology (Ardies et al., 2015). The six constructs of the attitude to technology were measured on a 5-point Likert scale described by Rupnik and Avsec (2019): (1) "Technological career aspirations (TCA) – four items, (2) interest in technology (IT) – six items, (3) boredom with technology (TTT) – four items, (4) beliefs about gender differences (TS) – three items, (5) perceived consequences of technology (CT) – four items, and (6) perceived difficulties of technology (DT) – four items" (p. 50).

For the purpose of interpreting the data, equal distances between points on a scale ranging from 1 (*very unlikely*) to 5 (*very likely*) were assumed. The scale does not represent the mean value, but the data obtained from the scale more closely approximates interval data (Hodge & Gillespie, 2007).

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The Cronbach's alpha coefficient values, which were all >.60 (Kubiszyn & Borich, 2013), show that the instrument used in the research was considered as reliable. Because of the heterogeneous nature of TL test–retest reliability, a supplementary time-reliability condition was proposed. The test and retest scores were significantly positively correlated (intra-class correlation coefficient *ICC* =.68, *p* <.05), indicating that the test is moderately reliable over time (Koo & Li, 2016). Table 2 shows reliability information on the instruments used in this research.

A test discrimination index, Ferguson's δ, was calculated on the assumption that the measurement is valid and reliable, for both pre- and post-test TL (.971 and .986, respectively). This "measures the discriminatory power of an entire test by investigating how broadly the total scores of the sample are distributed over the possible range" (Ding et al., 2006, p. 6). Ferguson's δ coefficient was >.9, indicating a high level of test discrimination (Ding et al., 2006).

Table 2
Reliability information expressed using Cronbach's a for the TL testing and the Technology and Me questionnaire. Test-retest reliability ICC was calculated for the TL testing

Scale (subscale)	**Cronbach's α**	ICC	Number of items
Technological literacy test:			
Technological literacy (total) - TL	74.3	.68	35
Technological knowledge - TK	67.3	.61	11
Technological capacity - TC	62.2	.59	12
Critical thinking and decision-making - CTDM	60.7	.57	12
Technology and Me questionnaire:			
Technological career aspirations - TCA	92.1		4
Interest in technology - IT	77.2		6
Boredom with technology - TTT	80.0		4
Beliefs about gender differences - TS	93.3		3
Consequences of technology - CT	78.8		4
Difficulty of technology - DT	78.0		4

Procedure and Data Analysis

Students were involved in the research during the planned teaching units. Testing using the *Technology and Me* questionnaire took 10-15 minutes and was followed by a TL test which took 30-35 minutes. One school period was used for the pre-test, and another was used for the post-test. The pre-test was carried out before the implementation of educational approach, and the pre-test was carried out after the completion of the last educational intervention in both experimental and control group in the 35th week. The presence of a teacher, researcher, and test administrator ensured a high response rate. In total, 242 participants completed both a test and questionnaire in the pre-test and post-test sessions.

Data were analysed using SPSS software (v.25). Descriptive analyses were used to analyse the students' basic information and obtain the mean scores for the dependent variables. A two-way ANOVA with repeated measures was used to compare pre- and post-test scores, which were also plotted for descriptive purposes. A multivariate analysis of variance (MANOVA) was conducted using the five attitude subscales and the concept scale to determine whether students' attitudes towards technology were affected by the educational approach. A MANOVA was also used to determine differences in TL and attitudes towards technology by gender across the educational approaches, with the effect size calculated using partial eta squared (η^2).

Several studies have examined the various isolated constructs, while the highly complex interactions between them have not been analysed. In TL research, it is important to evaluate the multiplied effects of the variables (Avsec & Jamšek, 2016; Gu et al., 2019; Rohaan et al., 2012), as well as the effects of student attitudes (Ardies et al., 2015; Gu et al., 2019). Therefore, a multivariate design in which all subfactors are modelled simultaneously is

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essential to correctly interpret the effects (Ardies et al., 2015).

The average normalized gain ⟨*g*⟩ of the class was calculated as a measure of the model's effectiveness in developing TL. The ⟨*g*⟩ is defined as "the average actual gain divided by the maximum possible gain, where G is the actual gain and ⟨%post⟩ and ⟨%pre⟩ are the final (post-test) and initial (pre-test) class averages, and the angled brackets ⟨… ⟩ represent the average score of the students taking the tests" (Colt et al., 2011, p. 210):

$$\langle g\rangle = \langle \%G\rangle / \langle \%G\rangle_{max} = [\langle \%post\rangle - \langle \%pre\rangle]/[100\% - \langle \%pre\rangle]. \quad (1)$$

Research Results

Technological Climate

It was found that about two-thirds of parents had not continued on to tertiary education (ISCED<5). The majority of students (52.1%) indicated that their father's job had "much" or "very much" to do with technology, while only 12.8% felt that their father's job had "nothing" to do with technology. In contrast, 14.1% of the students thought that their mother's job involved technology, while 66.5% believed that their mother's job had "little" or "nothing" to do with technology. Most students (80.6%) had some type of technical toy or construction set such as Lego, Fischertechnik or Automat in the home. Only 29.8% of the students cited advanced use of computers, and half of the students indicated that a technical workshop existed in their home.

Only 28.9% of the students expected to select a technological profession, while only 16.9% of students participated in technical activities outside of school. A large majority of students (81.3%) spent up to two hours per week preparing for their design and technology classes. Approximately one-third of students took at least one technology education subject as an elective in grades 7–9.

Given the prevalence of technology in the students' environment, the fact that only 28.9% of students expected to pursue a technological profession suggests that students do not really understand the importance of technology in most professions.

Differences in Students' Attitudes to Various Educational Approaches

The mean difference was calculated as the difference between the average rating in the pre-test and the post-test to detect differences in students' attitudes towards technology. Levene's test for equality of variances showed no statistical significance at the .05 level for all subscales of students' attitudes towards technology using both mean- and median-based calculations.

A MANOVA was conducted using the six attitude subscales to determine whether students' attitudes towards technology were affected by the educational approach. Statistically significant differences ($p<.05$) were found in relation to technological career aspirations ($F=3.441$, $p=.034$, partial $\eta^2=.031$) and perceived difficulty of technology ($F=3.823$, $p=.023$, partial $\eta^2=.034$). An ANOVA and Scheffe post hoc test were used to identify differences between the educational approaches.

The ANOVA on the technological career aspirations subscale found that the traditional approach differed significantly from the transdisciplinary approach on level 2 using the post-test means ($p=.04$). The mean score for the traditional approach was highest, suggesting that students perceived traditional teaching of design and technology subject matter as the most appropriate way to promote technical professions. While students' attitudes in general became less favourable towards technology, the greatest change over the 35 educational periods occurred in the transdisciplinary level 2 programme.

For the perceived difficulty of technology subscale, the level 2 transdisciplinary approach differed significantly from the traditional approach using the post-test mean scores. Students who experienced the transdisciplinary approach reported lower scores in terms of perceived difficulty of technology after the intervention, while there was little or no change in the scores of students who experienced the traditional approach. This difference may be related to the interdisciplinary-embedded topics studied in the level 2 programme. Table 3 presents all pre-test and post-test subscale average ratings expressed as mean scores.

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Table 3
Comparison of pre- and post-test means for each subscale by educational approach

Technology and Me subscales	Educational approach								
	Traditional (*n*=83)			Transdisciplinary level 1 (*n*=65)			Transdisciplinary level 2 (*n*=94)		
	Pre-test *M*	Post-test *M*	*p* value	Pre-test *M*	Post-test *M*	*p* value	Pre-test *M*	Post-test *M*	*p* value
Technological career aspirations -TCA	2.12	2.31	.073	2.69	2.61	.511	2.56	2.41	.072
Interest in technology -IT	2.99	2.98	.966	3.26	3.24	.866	3.09	2.95	.084
Boredom with technology - TTT	2.09	2.10	.978	2.04	2.03	.998	2.14	2.35	.022
Beliefs about gender differences - TS	3.05	2.81	.09	2.87	2.66	.228	3.47	3.31	.206
Consequences of technology - CT	3.70	3.64	.506	3.92	3.94	.915	3.81	3.74	.361
Difficulty of technology - DT	2.76	2.75	.553	2.77	2.46	.009	2.64	2.33	.006

Note: Statistically significant differences are shown in bold.

Pre- and post-test data from each of the three educational approaches were analysed to determine changes within the programmes over the 35-week treatment period. *T*-tests were run on all of the *Technology and Me* subscales, and no significant differences were found in relation to the TCA, IT, TS, and CT subscales for any of the educational approaches. Two subscales in transdisciplinary level 2 showed significant changes. The change in TTT was in a negative direction, meaning that students perceived technology as more tedious following treatment (effect size η^2=.55). This approach also showed a significant positive change in the perceived difficulty of technology subscale (effect size η^2=.80). The students felt that technology was more difficult to handle at the beginning of the programme than at the end of the 35-week treatment period. There were no statistically significant changes in any of the subscales under the traditional approach, although there were some changes in students' attitudes on the *difficulty of technology* subscales over the treatment period where transdisciplinary level 1 was used (effect size η^2=.102). Students in this group experienced low-level tasks, where technology was embedded in different ways in real-life contexts and the design and technology subject matter was not perceived as particularly difficult.

Gender Differences in Students' Attitudes towards Technology

There were 122 girls and 120 boys in the sample. Mean differences between pre-test and post-test responses were calculated for each subscale. A MANOVA test revealed no significant differences between girls and boys in relation to each educational approach. However, there were significant differences on two subscales, as shown in Table 4. The results of the MANOVA test suggested that girls were less inclined than boys to believe that technology was integrated with other disciplines, which is supported by girls responding more negatively after treatment on the interest in technology subscale in transdisciplinary level 2. After treatment in the level 1 group, girls responded less favourably than boys in relation to the CT subscale.

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Table 4
Comparison of attitude changes expressed as the mean differences between average pre- and post-test ratings for each educational approach by gender

Technology and Me subscales	Educational approach								
	Traditional (*n*=83)			Transdisciplinary level 1 (*n*=65)			Transdisciplinary level 2 (*n*=94)		
	Girls *n*=46	Boys *n*=37	*p* value	Girls *n*=30	Boys *n*=35	*p* value	Girls *n*=46	Boys *n*=48	*p* value
Technological career aspirations - TCA	0.12	0.28	.457	0.03	-0.17	.385	-0.26	-0.06	.282
Interest in technology - IT	-0.01	0.00	.970	-0.18	0.12	.110	-0.28	0.09	.049
Boredom with technology - TTT	0.08	-0.09	.453	0.16	-0.14	.259	0.29	0.16	.525
Beliefs about gender differences - TS	-0.19	-0.33	.621	-0.1	-0.29	.577	-0.23	-0.11	.575
Consequences of technology - CT	-0.07	-0.05	.919	-0.21	0.20	.047	-0.11	-0.04	.682
Difficulty of technology - DT	-0.03	-0.16	.556	-0.32	-0.26	.755	-0.35	-0.25	.623

Note: Statistically significant differences are shown in bold.

A MANOVA test of the combined pre- and post-test data for all subscales was used to identify differences in responses that may be attributable to gender. Statistically significant differences were found in relation to four subscales: technological career aspirations, interest in technology, boredom with technology, and beliefs about gender differences. The results are shown in Table 5.

Table 5
Differences in perceptions of technology attributable to gender

	Girls (*n*=122)		Boys (*n*=120)		*p* value	Effect size η^{2*}
Technology and Me subscales	*M* [/]	*SD* [/]	*M* [/]	*SD* [/]		
Technological career aspirations - TCA	2.01	0.72	2.88	0.95	<.001	.21
Interest in technology - IT	2.76	0.67	3.38	0.73	<.001	.16
Boredom with technology - TTT	2.36	0.80	1.91	0.67	<.001	.09
Beliefs about gender differences - TS	2.62	1.21	3.51	0.98	<.001	.15
Consequences of technology - CT	3.75	0.67	3.83	0.71	.412	.00
Difficulty of technology - DT	2.46	0.68	2.50	0.67	.627	.00

Notes: Statistically significant differences are shown in bold.
** η^2 as a measure of effect size is divided into small effect (.01 ≤ η^2 < .06), medium effect (.06 ≤ η^2 < .14) and large effect (.14 ≤ η^2).*

This procedure revealed that girls and boys perceived technology differently. Girls are more prone than boys to perceive design and technology as the context for both boys and girls, while boys have a greater intention to pursue a technical profession, are more interested in the design and technology, and are not as bored with technology as girls. With the exception of the transdisciplinary level 2 approach, the educational approaches that were used did not change these perceptions over the 35-week programme. All students found design and technology less difficult after experiencing technological learning activities.

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Differences between Educational Approaches in Relation to Students' TL

The first objective was to identify differences among the three groups of students who experienced different educational approaches. Table 6 shows the average overall TL scores and those in the three subdimensions.

Table 6
Comparison of pre- and post-test TL, both overall and in relation to the three subdimensions, by educational approach

Technological literacy	Test	Educational approach: Traditional (*n*=83)		Transdisciplinary level 1 (*n*=65)		Transdisciplinary level 2 (*n*=94)		Total (*n*=242)	
		M (%)	*SD (%)*	*M (%)*	*SD (%)*	*M (%)*	*SD (%)*	*M (%)*	*SD (%)*
TL total	Pre-test	35.93	11.46	35.34	11.73	33.37	10.86	34.78	11.31
	Post-test	34.39	11.63	45.58	12.97	46.05	13.31	41.92	13.73
TK	Pre-test	52.57	18.89	54.68	18.56	50.87	16.45	52.47	17.88
	Post-test	50.38	19.22	64.33	17.25	62.09	15.58	58.67	18.31
TC	Pre-test	30.52	13.79	26.66	12.94	26.15	15.67	27.78	14.42
	Post-test	26.80	12.68	37.05	18.28	36.79	17.51	33.43	16.88
CTDM	Pre-test	26.10	14.88	26.28	15.11	24.55	13.84	25.55	14.51
	Post-test	27.31	16.68	36.92	16.01	40.61	17.54	35.05	17.75

Note: M represents the mean, SD represents the standard deviation, and n represents the number of students.

Levene's test for equality of variances showed no statistical significance either pre-test (F (2, 239)=0.495 (p=.610)) or post-test (F (2, 239)=0.764 (p=.467)). This suggests that data are normally distributed (p>.05).

A two-way ANOVA with repeated measures was performed to test within-subject contrasts in relation to how different educational approaches in design and technology classes enhanced TL. Some statistically significant results were found, as shown in Table 7.

Table 7
Tests of the differences in learning achievements between the treatment and control groups over the research period

Source	Test	Type III Sum of Squares	*df*	s^2	*F*	*p*	η^2*
Test	level 1 vs. level 2	11992.53	1	11992.53	130.16	<.001	.353
Test * Group	level 1 vs. level 2	9771.39	2	4885.69	53.02	<.001	.307
Error (test)	level 1 vs. level 2	22020.44	239	92.13			

Note: df denotes the degrees of freedom, s^2 denotes the square of the mean, F-variation between sample means / variation within the samples, and η^2 denotes the effect size.
** η^2 as a measure of effect size is divided into small effect (.01 ≤ η^2 <.06), medium effect (.06 ≤ η^2 < .14) and large effect (.14 ≤ η^2).*

The groups showed significant changes (p<.001) from pre-test to post-test with a large effect size (η^2=.353). The transdisciplinary approach had a statistically significant impact on TL acquisition (p<.001) with a large effect size (η^2=.307).

Scheffe post hoc testing revealed significant differences between the level 2 group and the traditional teaching group (p=.025) and between the level 1 group and the control group (p=.016). There was no significant difference between the two experimental groups (see Figure 1). The maximum possible score on the test was 35 points.

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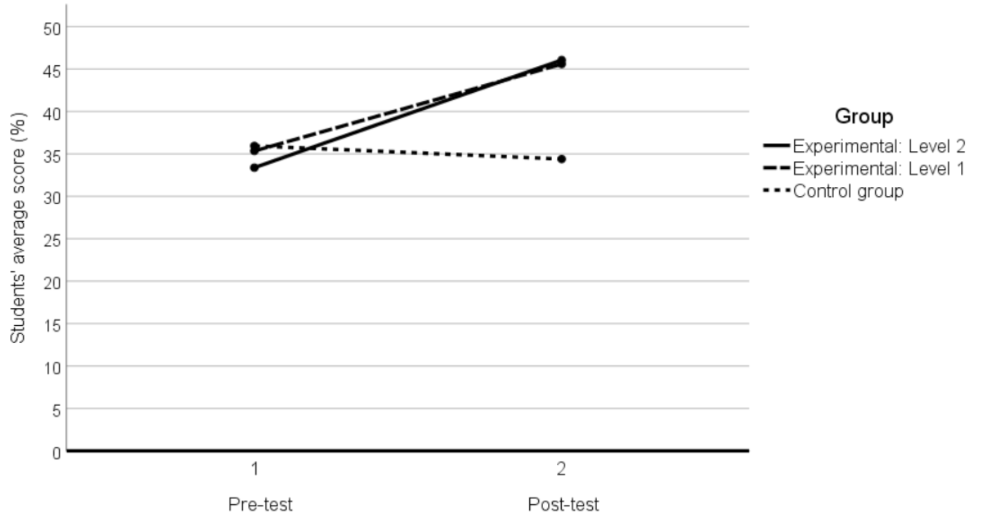
Figure 1
Mean pre- and post-test technological literacy scores



This quasi-experimental, three-group pre-test/post-test research was designed to assess learning gains expressed in terms of TL and the effectiveness of this 35-week (one period per week) design and technology course. It was demonstrated how various learning measures, including class-average normalized gain, can be used to measure the acquisition of TL. It was hypothesized that the transdisciplinary educational intervention would result in significant gains in TL and its subdimensions of TK, TC, and CTDM.

In addition, the class-average normalized gain $\langle g \rangle$ was calculated using Eq. 1. Table 8 shows the average gain in overall TL and in the subdimensions.

Table 8
Comparison of average TL gains by educational approach

Technological literacy	Educational approach: Traditional (*n*=83)		Transdisciplinary level 1 (*n*=65)		Transdisciplinary level 2 (*n*=94)		Total (*n*=242)	
	M (%)	*SD (%)*	*M (%)*	*SD (%)*	*M (%)*	*SD (%)*	*M (%)*	*SD (%)*
TLtotal	-4.07	20.47	15.99	12.65	19.37	14.38	10.41	19.41
TK	-22.23	86.98	16.18	44.01	18.14	35.61	3.77	62.71
TC	-9.21	27.91	14.33	22.68	12.76	26.01	5.65	27.91
CTDM	-1.72	29.65	11.01	30.82	21.20	20.19	10.60	28.37

Note: *M* represents the mean, *SD* represents the standard deviation, and *n* represents the number of students.

Levene's test for equality of variances found no statistical significance for TL_{total} and the subscales TC and CTDM ($p>.05$), while for the subscale TK, non-homogenous variances were detected across all educational approaches ($p=.003$). This confirmed that the research sample did not violate the assumption of normality in relation to TL_{total}, TC and CTDM, where differences between educational approaches were found using the Scheffe post hoc test. For TK, Levene's test revealed non-equal variances across the groups, thus the Games-Howell post hoc test was used to identify significant differences.

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To determine whether students' TL was enhanced by the educational approach, a MANOVA was conducted on the overall TL and its subscales. Statistically significant differences were found in relation to the component scale and all subscales. The results are shown in Table 9, which shows statistically significant differences with a large effect size for TL_{total} and TC (.297 and .149, respectively), while for TK and CTDM, the effect size is medium (.09 and .119, respectively). Analysis of variance using both Scheffe (equal variances assumed) and Games-Howell (equal variances not assumed) post hoc tests was used to identify differences between the educational approaches.

Table 9
Tests of the differences between educational approaches in terms of TL gains

Source	Test	Type III Sum of Squares	*df*	s^2	*F*	*p*	η^{2*}
Group	⟨g⟩ TLtotal	26972.58	2	13486.29	50.45	<.001	.297
	⟨g⟩ TK	85513.42	2	42756.71	11.84	<.001	.090
	⟨g⟩ TC	27952.43	2	13976.21	20.91	<.001	.149
	⟨g⟩ CTDM	23168.21	2	11584.10	16.20	<.001	.119

Note: df denotes degrees of freedom, s^2 denotes the square of the mean, F-variation between sample means/variation within the samples, and η^2 denotes the effect size.
** η^2 as a measure of effect size is divided into small effect ($.01 \le \eta^2 < .06$), medium effect ($.06 \le \eta^2 < .14$) and large effect ($.14 \le \eta^2$).*

A Games-Howell post hoc test revealed significant differences in terms of students' TK gains between the traditional teaching approach and both level 1 and level 2 transdisciplinary approaches (*p*=.02 and *p*<.001, respectively). The transdisciplinary approaches were more effective than the monodisciplinary teacher-centred approach, where students showed a decline in TK. No differences were found in relation to TL gains between the level 1 and level 2 transdisciplinary approaches.

A Scheffe post hoc test revealed significant differences in terms of students' TC gains. Once again, both of the transdisciplinary approaches were significantly different from the traditional approach (*p*<.001), but no significant differences were found between the level 1 and level 2 transdisciplinary approaches.

A Scheffe post hoc test also identified significant differences in terms of students' CTDM gains, whereby students in both experimental groups (level 1 and level 2) significantly outperformed students in the control group (*p*=.017 and <.001, respectively). A difference was also found between the level 1 and level 2 transdisciplinary approaches (*p*=.047). Thus, it seems that high cognitive level tasks might enhance students' CTM ability.

The transdisciplinary approaches were also significantly different from the traditional approach in terms of gains in overall TL (*p*<.001).

Differences in TL Gains by Gender

The sample included 122 girls and 120 boys. An analysis of variance of TL gains showed no significant differences (*p*>.05) between girls and boys, with means of 9.05 (*SD* 20.69) and 11.81 (*SD* 18.01), respectively. Using type of educational approach as a covariate, a multivariate analysis of covariance also revealed no significant differences (*p*>.05) in students' TL gains when the combined effects of gender and type of educational approach on TL gains were considered.

Moreover, there were no significant differences among the programmes in terms of students' TL gains based on gender, as shown in Table 10. Thus, none of the three educational approaches were gender sensitive, although girls scored higher in the CTDM category in the level 1 transdisciplinary approach. This difference can be attributed to the unknown influencers.

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Table 10
Comparison of students' TL gains under each educational approach by gender

Educat. appr.	Gender	TL_{total} gain			TK gain			TC gain			CTDM gain		
		M [%]	SD [%]	*p*	*M* [%]	*SD* [%]	*p*	*M* [%]	*SD* [%]	*p*	*M* [%]	*SD* [%]	*p*
Tradit. *n*=83	Girls *n*=46	-5.14	23.01	.59	-25.27	103.81	.72	-11.41	30.02	.42	-2.06	30.07	.91
	Boys *n*=37	-2.74	16.98		-18.44	61.13		-6.45	25.14		-1.29	29.53	
Trans. level 1 *n*=65	Girls *n*=30	17.02	14.37	.54	18.16	32.22	.74	10.50	20.70	.21	19.01	22.66	.06
	Boys *n*=35	15.08	11.09		14.48	52.48		17.59	24.07		4.14	35.28	
Trans. level 2 *n*=94	Girls *n*=46	18.03	12.5	.38	17.97	39.51	.96	10.63	19.70	.44	20.62	18.17	.79
	Boys *n*=38	20.64	15.99		18.28	31.86		14.79	30.96		21.74	22.14	

Other Possible Internal and External Influences on Students' TL Gains

A quasi-experiment was conducted over 35 weeks throughout the school year during which one period per week was devoted to the implementation of various educational approaches. It is understandable that some other factors besides the educational approach might affect students' TL gains. Thus, several other covariates, for example, home environment characteristics, learning habits, out-of-school activities and attitudes towards technology were analysed.

Multiple regression analysis with multiple dependent variables was performed using MANCOVA in an attempt to determine how much the independent variables could predict student TL and its dimensions. The results showed that the combination of independent variables was significantly positively correlated with student TL_{total} gains (F (17, 224) = 2.698, p<.001). Approximately 17% of the variance in student TL gains was accounted for by the 17 predictor variables. The explained variances were calculated with R^2, whereby Cohen et al. (2003) proposed R^2 values as effect size for the evaluation of endogenous variables: .26 (substantial), .13 (moderate) and .02 (weak). Regarding the effect of external attributes on explained variances in TL gains, the effect is estimated as medium. Thus, these attributes do not reduce the effectiveness of the transdisciplinary educational approach that is validated in this research.

To determine which influencers affected students' TL gains, a multiple regression analysis was carried out using a range of items including students' grade point average, technical elective courses, preparation time for design and technology classes, out-of-school technical activities, aspirations for technical professions, home environment characteristics, perceived attitudes towards technology as the independent variables and students' gains in TL_{total}, TK, TC, and CTDM as the dependent variables.

A linear relationship between the predictor and criterion variables was assumed, hence it was expected that an increase in one variable would be associated with an increase or decrease in another variable. The standardised regression coefficients Beta (β) weights "describe the relationship between a predictor variable and a criterion variable after the effects of other predictor variables have been removed" (Paechter et al., 2010, p. 224). The β weights usually range in absolute value from 0 to 1 (Cohen et al., 2003). Multiple regression used in this research "does not explain causes and effects, rather it describes the relationships between variables or sets of variables" (Paechter et al., 2010, p. 224). Thus, the results should be interpreted with a cautious. Table 11 presents a summary of multiple regression analyses with significant β weights.

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Table 11
Summary of multiple regression analysis of students' overall TL gains and gains in the TK and CTDM subdimensions using various internal and external influences

Importance of:	Acquisition of technological literacy:								
	TL_{total}			TK			CTDM		
	β	*t*	*p*	β	*t*	*p*	β	*t*	*p*
Job mother	-0.17	-2.45	.014	-	-	-	-0.15	-2.17	.030
Home workshop	0.18	2.74	.007	-	-	-	0.13	1.98	.049
Use of home computer	-0.13	-1.98	.048	-0.15	-2.11	.035	-	-	-
Aspirations for technical professions	0.24	2.74	.006	-	-	-	0.16	2.01	.046
Perceived difficulty of technology	0.16	2.42	.016	0.18	2.71	.007	-	-	-

Note: β–weight, t–statistics. Students' gains in the TC dimension were not statistically significantly affected by the investigated factors (p>.05).

Multiple regression analysis was performed to determine the differences in the answers that may be due to internal and external factors of the students. The results indicated statistically significant effects of external factors including parental profession, home workshop and home use of computers, and internal factors including aspirations to pursue a technical profession and perceived difficulty of technology. The results are shown in Table 11. Only five of the 17 factors that were investigated were found to have affected TL acquisition, with an effect size estimated as small to medium. As expected, students' motivation to pursue a technical profession had a large effect, while students' perceptions of difficulty of technology did not reduce their interest in learning the design and technology subject matter. After three years spent attaining competence in design and technology, they did not underestimate the complexity of technical operations as learning tasks. They were aware that the acquisition of knowledge and skills in technology education is mostly oriented towards active learning using a constructivist approach, hands-on experience, the trial-and-error method, working with and processing different materials, reverse engineering, and repairing different technological artefacts.

The home environment seems to be a negative predictor of students' acquisition of TL. There were two noteworthy findings, namely, a mother's technical orientation did not influence students' TL development, and students' who used home computers for technical drawing, 3D modelling and programming experienced smaller gains in TL, especially in TK.

There was one positive predictor of TL acquisition in the home environment; a home workshop where students could tinker with, repair, maintain and create various technological artefacts. This was expected, because students' CTDM is enhanced when tasks are presented in a real-world context.

Several other factors did not significantly affect students' acquisition of TL, including students' attitudes towards technology (except for their aspirations to pursue a technical profession and perceived technology difficulty), choosing technical elective subjects, time spent on preparation for design and technology classes, grade point averages, participation in out-of-school technical activities and having technical toys and construction sets in the home.

Discussion

The quality of technology education on a large scale depends on the curriculum, which should be competitive enough to improve employability in the labour market in the technological society. The main purpose of this research was to explore whether transdisciplinary approach in lower secondary school technology education enhances TL as the main learning achievement and as a measure of student competitiveness.

In answer to the first research question posed in the research protocol, the results revealed that transdisciplinary teaching differs significantly from traditional teaching as measured on the perceived difficulty of technology and boredom with technology subscales. As expected, there were no differences in students' attitudes compared with the traditional teaching approach, confirming the findings of several previous studies (Ankiewicz, 2018; Rupnik & Avsec, 2019; Zhou et al., 2019). Moreover, transdisciplinary teaching only had a moderate effect size in relation to at-

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titude changes measured using η^2. This may have been caused by the nature of the lessons, which were designed to expose students to real-life problems wherein they were exposed to both the positive and negative consequences of using technology to modify the social, economic and natural environments to meet humans' needs and wants. Thus, students gained a more balanced view of technology, and were more ready to accept the consequences of technology. The students of the transdisciplinary programme seemed to have a better understanding of the way technology is used in different disciplines, e.g. in the natural sciences, mathematics and social sciences, which were integrated into new concepts and contexts.

The research also revealed some differences in attitude changes after the experiment. As expected, no differences were found in the attitudes of students who had experienced the traditional approach, while boys who had experienced the level 2 transdisciplinary approach showed increased interest in technology. Previous research has shown that the combination of different disciplines and knowledge creation was found to be more effective with girls (Virtanen, Räikkönen, & Ikonen, 2015). Nevertheless, the effect was weak, and could have been caused by changes in perceptions of technology, whereby girls are more likely to attend transdisciplinary rather than traditional classes, leading to a shift in the quantification of students' perceptions of technology (Ankiewicz, 2018; Ardies et al., 2015).

An analysis of average pre-test and post-test self-assessed attitudes revealed that the perceptions and attitudes of girls and boys differed significantly. Boys were more likely to pursue a career in a technical profession, have a greater interest in technology, be less bored by technology, and believe that technology was only for boys. These findings were also consistent with those of previous studies, for example, Virtanen et al. (2015), who showed that girls preferred environmental studies, required more support from teachers and preferred to create more decorative products rather than technically useful, functional products. Boys appear to be more self-confident, display a greater degree of self-efficacy, and put more effort into learning the design and technology subject matter. Of the three educational approaches, only the level 2 transdisciplinary approach increased this perception.

Transdisciplinary approaches have a significant influence with a large effect size (η^2=.297) on students' development of TL. It seems that approaches used in experimental groups affected both the creation of new knowledge and the skills needed to elicit knowledge from other disciplines, consistent with the findings of Norden (2018) and Slavinec et al. (2019). As expected, there were no significant changes in TL development in the teacher-centred educational approach, in which the context and content is not adequately covered in the STL (Avsec & Jamšek, 2018). Both transdisciplinary levels were almost equally effective, with the only differences found in relation to the CTDM dimension of TL, wherein high cognitive level tasks enhance students' critical thinking ability. Neither of the transdisciplinary models were gender sensitive, thus the level of TL improved in both girls and boys. This points to increased enrolments of girls in technical and engineering courses, which may enhance social interactions, creativity and innovation capabilities among both individuals and teams.

An analysis of various external influences on TL acquisition revealed that only 17% of the variance was explained by these factors. Thus, it seems that the results found in this research are not biased. Further, the use of home computers is time-consuming, and not particularly connected with technological concepts, and thus did not serve to advance students' TK. It was also found that mothers spent more time working with their children than fathers, confirming the findings of Ardies et al. (2015), and thus mothers with non-technical professions affected their children's TL acquisition, especially in the CTDM dimension. The home technical environment and aspirations for a future career in a technical profession may enhance students' TL acquisition. No significant effect from choosing technical elective subjects was found, nor was participation in out-of-school technical activities effective in increasing students' TL. It seems that out-of- school technical activities are oriented more towards technical practice, rather than broader technology issues, and time spent preparing for design and technology lessons was used to memorize facts and low-level concepts, confirming the findings of several previous studies (Gu et al., 2019; Luckay & Collier-Reed, 2014) and providing additional support for the findings of Doyle et al. (2019) and Rossouw et al. (2011) regarding new teaching approaches aimed at enhancing the development of TL rather than the development of algorithm- and rules-based technical practices.

Conclusions

This research confirms the importance and effects of transdisciplinary educational approach in the development of TL. An analysis of the current understanding of the nature and objectives of STEM teaching suggests that a transdisciplinary approach to education could improve TL as the main outcome of a redesign of technology education. Based on the results of this research, the following conclusions can be drawn: (1) a transdisciplinary approach in a technology classroom over a 35-week course affected students' attitudes towards technology, and in particular

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the perceived difficulty of technology was reduced, (2) a transdisciplinary approach delivered at a higher cognitive level increases students' interest in technology and awareness of the consequences of technology, especially boys, (3) students experiencing transdisciplinary teaching perceived the design and technology subject matter in broader terms, although misconceptions regarding what comprises technology remain, (4) transdisciplinary teaching and learning enhance TL as defined by the ITEA, (5) a new model for developing TL enhances TL in both girls and boys, (6) the home environment affects the development of students' TL in both directions, that is, home workshop activities improve the acquisition of TL, while use of computers at home may reduce the acquisition of TL, and (7) the present design and technology curriculum needs changes, and more active teaching methods using real-life contexts and concepts should be included to support the development of higher-order thinking skills.

In addition, the results can also be interpreted to indicate the need for students to have sufficient knowledge and skills to be able to learn in a way that supports the creation of new knowledge and the acquisition of higher-level thinking skills that go beyond current curriculum standards.

A deep understanding of how technology, the natural environment and society are interconnected and create synergies in relation to sustainability initiatives can be used to drive transdisciplinary-oriented curriculum changes.

Recommendations and Future Work

On the basis of the findings and conclusions of this research, the following recommendations are proposed: (1) regardless of the educational approach, STEM educators should assess students in both cognitive and affective domains to assess their acquired knowledge and skills together with attitude changes, (2) curriculum designers and STEM teachers should make efforts to develop a curriculum that satisfies the interests and technological needs of all students, (3) technology education curriculum developers should consider both the ITEA's STL and the concepts and contexts proposed by Rossouw et al. (2011), which will enable the delivery of more transdisciplinary subject matter to reduce the inequalities being created by the current megatrends.

Future research will be oriented towards identifying how STEM teachers perceive transdisciplinarity and how their self-efficacy affects the delivery of transdisciplinary content.

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Appendix A

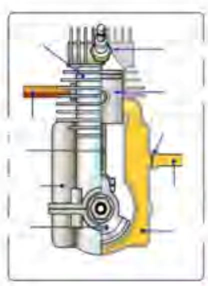
Stages of TL acquisition:	Learning outcomes- Student will be able to:	Task context:	A way of response:
1	- Know use of internal combustion engines (ICE).	3 examples needed	Motorcycle, tractor, car
2	- Indicate differences between gasoline and diesel ICE.		Fuel (gasoline, diesel); fuel ignition (spark plug, compression), …
3	- Detect possible engine ignition faults (too much exhaust emissions, damaging the environment).		In such case, it is necessary to check that there is sufficient fuel in the tank. Then check the spark plug function. Unscrew the spark plug and look at its top (it should be dry and rust free). Following is a tire pressure check ...
4	- Name and relate the engine parts.		Slotted cylinder, piston, connecting rod, ...
5	- Know which fuel is appropriate for a particular engine type.		In this case 95-octane gasoline…
6	- Estimate the value of workshop hour. - Calculate the value of spare parts.		A price of mechanical work is set appropriate. The price of piston rings is 10 €…

Figure A.1
Transdisciplinary approach Level 1 tasks for the acquisition of TL.

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Appendix B

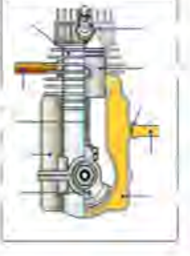
Stages of TL acquisition:	Learning outcomes - Student will be able to:	Task context:	A way of response:
1	- Know use of internal combustion engines ICE.	5 examples needed	Motorcycle, tractor, car, lawn mower, chainsaw
2	- Outline differences between gasoline and diesel ICE and its environmental impact.		Fuel (gasoline, diesel); fuel ignition (spark plug, compression). … In most cases, diesel engines are more polluting than gasoline.
3	- Detect possible engine ignition faults (too much exhaust emission, damaging the environment). - Know how to solve problems with particular technology of ICE.	 	In such case, it is necessary to check that there is sufficient fuel in the tank. Then check the spark plug function. Unscrew the spark plug and look at its top (it should be dry and rust free). Following is a tire pressure check, ... It is necessary to unscrew the spark plug and sand it with a sandpaper where the spark occurs.
4	- Name the engine parts. - Analyse the picture and categorise the engine parts.		Slotted cylinder, piston, connecting rod, ... Two-stroke gasoline engine.
5	- Know which fuel is appropriate for a particular engine type and why. - Assess the ratio of oil to gasoline. - Assess the consequences of bad decisions.		In this case, gasoline and engine oil. Mixture of 5 % engine oil and 95 % gasoline. If pure gas is poured instead of the mixture, the engine will warm up and eventually turn off because it will not receive the "lubricant" for the moving parts.
6	- Determine the value of spare parts. - Know how to set a price of mechanical work and to evaluate it. - Think critically about the time needed to replace the piston rings.		The value of parts is 10 €. If the price of spare parts is 10 €, it means that the price of the mechanical work would be 90 €, which is very high, since the worker is supposed to spend 1 hour in total. With the help of critical thinking, the result would be that replacing piston rings with work is worth approximatelly 30-40 €.

Figure B.1
Transdisciplinary approach Level 2 tasks for the acquisition of TL.

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