sustainability

Article

Mapping the Relationships between Self-Directed Learning and Design Thinking in Pre-Service Science and Technology Teachers

Stanislav Avsec * and Vesna Ferk Savec

Faculty of Education, University of Ljubljana, Kardeljeva Ploscad 16, SI-1000 Ljubljana, Slovenia; vesna.ferk@pef.uni-lj.si
* Correspondence: stanislav.avsec@pef.uni-lj.si; Tel.: +386-15892200

Abstract: Self-directed learning and design thinking were found to be promising pedagogies for supporting education and thus supporting sustainable development goals. While some researchers have posited that self-directed learning may support design thinking, empirical research examining the relationship between these two essential skills is lacking because their shared conceptual structure has not been articulated in detail, and because they have remained siloed in design practice. This study examines pre-service teachers' self-regulation in relation to design thinking skills to advance a theoretical understanding of design science and to overcome challenges teachers face in adopting and implementing design thinking. For this study, 158 pre-service teachers were recruited. On the first level, the empirical data collected were subjected to structural equation modelling to find and confirm significant metacognitive perspectives in design thinking, while on the second level, an in-depth analysis was conducted to find moderating effects of pre-service teachers' metacognitive experiences and teacher education in design thinking. We argue that awareness and interpersonal skills are crucial in creative design activity, and that embracing risk, tolerance to uncertainty, and underdeveloped supervising skills might be critical elements for advancing design thinking behaviour. The findings of this study have implications for effective science and technology teaching and the learning of design thinking in teacher education, and for educators and commercial course designers to adjust the implementation of design thinking.

Keywords: design cognition; design metacognition; design thinking; self-directed learning; innovative pedagogy; pre-service science and technology teacher

check for updates

Citation: Avsec, S.; Ferk Savec, V. Mapping the Relationships between Self-Directed Learning and Design Thinking in Pre-Service Science and Technology Teachers. *Sustainability* **2022**, *14*, 8626. https://doi.org/10.3390/su14148626

Academic Editor: Antonio P. Gutierrez de Blume

Received: 18 June 2022
Accepted: 12 July 2022
Published: 14 July 2022

1. Introduction

The general concept of design thinking, as an iterative and non-linear process, can be seen as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve client's objectives or users' needs while satisfying a specified set of constraints." [1] (p. 2). Moreover, it is a human-centred approach to innovation, anchored in understanding customer's needs, rapid prototyping, and generating creative ideas, and it represents a set of cognitive, strategic, and practical processes by which design concepts are developed [2]. It centres on design cognition, which emphasizes the mental processes and representations involved in designing, such as design reasoning, processes and patterns, divergent and convergent thinking, design fixation, design creativity, visual reasoning in design, design space co-evolution, and design collaboration with design cognition tools [3,4].

Design thinking as an approach to teaching and learning has gained particular attention and has been exploited widely across the educational vertical, from elementary school to university education [5–7]. Design and research activities are becoming more important in national and international education curriculum standards [8]. Design thinking is considered a new paradigm for dealing with problems in real life and in different sectors of the economy—business, medicine, information communication—and in education, for meeting the challenges of Industry 4.0 and developing 21st century skills, such as critical thinking and problem solving, creativity and innovation, collaboration, flexibility, self-direction, social interaction, and leadership [5].

Behaviour design thinking integrates cutting-edge behavioural science with design thinking to drive innovation at the product, service, and experience levels, leading to success and business growth across industries [9]. Thus, design thinking is also considered a promising educational approach to dealing with complex, diverse, and often difficult problems that teachers and educators face in professional practice, ranging across teaching and learning topics, to social or community issues, classroom climate issues, and countless others [10–12]. Moreover, Henriksen et al. [12] suggest that design thinking may provide an accessible structure for teachers and educators to think creatively when coping with educational problems of practice, and may support and augment traditional critical thinking as argued by Ericson [2] and Kijima et al. [13]. Design thinking as a team-based learning process may offer teachers support towards practice-oriented and holistic modes of construct learning when active learning approaches are implemented, as argued by Scheer et al. [14]. Koh et al. [15] highlighted the design thinking skills that pre-service teachers need to effectively design lessons for individual differences, and to develop design capacity among future students.

Teachers should be able to enact design science as part of their normal professional practice and have the means to be design researchers themselves, as argued by Henriksen et al. [11] and Laurillard [16]. Moreover, design patterns were found to be a means for externalising knowledge to allow the accumulation and generalisation of solutions and memory recombination as in intuitive cognition [16,17]. Thus, well-designed and well-situated design thinking activities and tasks may help students reach the highest levels of the revised Bloom taxonomy [18] (synthesis and creation), valuing empathy, openness to uncertainty, decision making, and problem scoping as skills and traits highly in demand across industries and other sectors of the knowledge economy [2,11]. In this way, developed cognitive and metacognitive structures and schematic processes in students will affect their use of technological pedagogical approaches oriented toward design and thus determine the quality of science and technology education implementation, as argued by Lin et al. [19].

Despite the popularity and prevalence of design thinking in various disciplines, numerous researchers have reported its pedagogical problems [12,20–22], which are most likely due to a root problem in ineffective teaching and learning of the discipline [5,7,8,23,24]. Thus, implementing design thinking was found to be challenging and several problems were detected [10]. When teaching novices, especially from heterogeneous groups, problems were detected in the accelerated pedagogical model on how to effectively use human-centred design to solve vexing work or social problems. This is because novices' capacity for empathy, understanding user needs and behaviour, transdisciplinary learning and collaboration, and openness to uncertainty is rather low [6,10,20]. Novices and unwary designers may also struggle to follow iteration as an important design process, and they must develop the capacity for metacognition or awareness and understanding of internal thought processes to overcome cognitive traps in design thinking [9,25].

A lack of consumers' perspective is detected, not just in novices, but especially in accelerated courses for different students in study programmes or training [6]. Several training and education institutions offer courses focused on the accelerated model with case-based designs, or on design fixation in the slow or decelerated model, that aim to transform initial ideas analytically without considering alternatives [20,26]. Accelerated courses can be timesaving, accessible, and convenient; however, most are expensive, and are delivered in a duration of up to eight hours using different modalities such as online, face-to-face, blended, or hybrid workshops in order to reach wider audiences, increase popularity, and promote education or training [20,27]. For the effective development of metacognitive and cognitive structures in learners and their transformative learning, at least 40 h of instruction are needed in alignment with validated theories, as argued by Hochberg and Desimone [27] and Yang et al. [28]. Despite the limited long-term impacts of such organised workshops or training sessions, universities and other training providers promote themselves and their brands through design thinking.

Any design process requires real-time monitoring or supervision of tasks for the fine-tuning or adjustment of progress in design, but some literature suggests that design teachers/educators and learners have rather insufficiently developed abilities for supervision and monitoring [8]. Instead, they are focused on content knowledge and the supervision of research activities [8]. Moreover, a lack of pedagogical content knowledge and the practice of design thinking, especially in freshmen pre-service teachers, might cause biases in the perception of design thinking deliverables, as argued by Duffin et al. [29].

The pedagogy of design thinking can be also affected by inadequate resources, time constraints, a fear of poor grades, and the difficulty of shifting to a new way of teaching and learning that differs vastly from the traditional approach [30]. When performing design thinking, educators should focus on practising and receiving feedback from experts in the field. Without establishing the necessary culture and mindset, the desired results may not be obtained and the process may even fail [31]. Moreover, teachers and students must cooperate to find solutions; when collaboration is established, and the uncertainty and ambiguity inherent in the design process are tolerated by teachers, design thinking can foster students' reflection on and in action and on knowledge [10].

Acquiring new skills and upskilling is not a one-time deal. Rather, it requires well-developed cognitive and metacognitive structures to frame and shape design thinking behaviour [19]. Teaching and learning design thinking requires the right pace and time to unfold the layers of what it means to be human-centred [19,20,30]. In conceptual design, special attention should be paid to cognitive structures and processes such as long-term memory, semantic processing, visual perception, mental imagery processing, creative output production, and executive function, as claimed by Hay et al. [22].

If teachers and educators continue to ignore the tension between the demands of accelerated and decelerated learning with regard to cognitive and metacognitive structures, students will abandon design thinking as quickly as they try it, leading to a widespread lack of awareness of design thinking, along with misuse, misconception, and misattribution that limit its power and impact [20,32].

A way forward might be to cultivate self-directed learners of design thinking, especially in problem-seeking and resolution [33], starting with pre-service teachers who will teach design thinking to school students [10,19]. They will be taught to overcome cognitive traps and obstacles such as encoding failures, inattentional blindness, confirmation bias, fundamental attribution errors, and sunk cost traps [9]. Moreover, when designing, students must utilise their capacity for metacognition, or awareness and understanding of internal thought processes, to employ effective countermeasures [9,23] and to control iteration as 'a purposeful progression through stages of the design process' [25] (p.1). Such self-regulated learners of design thinking will be able to transform problematic frames of reference that guide action in order to make them more inclusive, discerning, open, reflective, and emotionally open to change [34]. Self-directed learners might also be able to make the shift from individual-oriented to collaborative learning, from intellectual to embodied, and from retrospective to prospective, as argued by Ericson [2] and Razzouk and Shute [35]. According to regulatory focus theory, two distinct types of regulatory systems, namely promotion and prevention focus [36], may drive the process of self-regulation in design activities, where the promotion focus represents a person's wishes, hopes and aspirations, while the prevention focus represents a person's obligations, duties and responsibilities [36,37]. Both dimensions of regulatory focus might influence pre-service teachers' perception, behaviour, performance, and emotions in design thinking, but may be affected by process feedback, task instruction, and goal framing [37,38].

1.1. Design Thinking in Teacher Education

Nowadays, many educational institutions are required to compete internationally and constantly strive for new and innovative approaches, methods, and strategies to teach and learn [39]. Since the nature of education and teaching is closely connected with design science [16], teachers should be designers of learning experiences [11,40]. Several deficits were found when teachers designed and implemented active learning experiences, e.g., a lack of knowledge and skills for structuring and scaffolding students' active learning efforts; the inability to identify the benefits of working together in collaborative tasks, especially transdisciplinary collaborations [41]; a lack of knowledge and skills about ICT and the tools they need; a lack of research skills to achieve dynamic interaction between the respective networks, communities, and actors involved in the education field's knowledge chains [42]; a lack of knowledge, skills, and experiences in designing fast and slow active learning to address persistent and complex problems [32]; a lack of knowledge of cognitive processes in conceptual design [22]; and a lack of embracing risk and sophisticated thinking strategy [12,33].

However, to overcome such serious deficiencies in teachers as classroom practitioners and designers of learning environments, a drastic rethink of both initial pre-service and in-service teacher education is needed. It is not only the curricula and pedagogy that must be changed; there must also be a major shift in the modes of thinking and behaviour of teachers and students, as argued by Retna [30].

Since active learning in science and technology education may be successfully framed with design thinking, teacher educators might employ dozens of design thinking models [11,19]. Studies suggest that a five-phase Stanford model of design thinking [43] might be embedded in teaching coursework, thereby also serving as a guiding approach for novice teachers [11]. Five basic phases serve as modes: (1) empathize, (2) define, (3) ideate, (4) prototype, and (5) test of solutions. Designers, teachers, and others can interact with each mode in different ways—forward and backward, single or multiphase—to understand or explore problems and solutions [11]. More often, the communication of solution and redesign is added as an extension to the original model, as stated by Lin et al. [19]. The design thinking model itself allows for different modelling, feasibility analyses, the development of creativity, interactions and collaboration, and transformative learning, which can improve pre-service teachers' capacity for sophisticated thinking [44] and the critical evaluation of ideas and conceptual variants. This later enables effective embodiment design and re-design, as argued by Ericson [2] and Lin et al. [19]. Design thinking is well supported in both social-cognitive and social-constructivist sciences, with activities which allow for the application of metacognition and high-level information-processing strategies to the organization of cognitive structures [7,19,23]. Learning concepts is a real challenge for learners due to the abstract nature of the concepts [8]. Moreover, when pre-service science and technology teachers perform real-life design-based active learning activities, they are provided with opportunities for expression, communication, and consultation, which improve their cognitive structures in design thinking [19]. Sophisticated thinking capacity as a combination of well-developed lower- and higher-order thinking skills will enable pre-service teachers as designers to effectively transition from simple to complex operations, from observable to abstract dimensions, from emphasis on working with known materials to unknown materials, and from traditionally used deductive/inductive thinking to abductive thinking, which leads to explanatory hypotheses [10,45]. Following the basic ontology in design thinking with the fundamental constructs of function (F), behaviour (B), and structure (S), a transformation from requirements into design description can be done through slow and fast design thinking modes [20], where a large amount of self-directed learning might be employed in the model. Self-directed learning can be used at intra- and interpersonal levels with self-awareness, initiative and ownership, goal setting and planning, engaging and managing, and monitoring and adapting ability, where learners can work in self-directed ways while engaged in group-learning settings, provided this is a choice they have made believing it to be conducive to their learning efforts [46]. Moreover, well-designed tasks that require students' active reflection rather than reflexive or reactive response, decision-making, and creation based on the transfer of team learning can foster higher-order thinking and strategic learners [47]. When pre-service teachers learn and use design thinking, they might gain the benefits of valuing empathy, openness to uncertainty and ambiguity, and seeing teaching as design [11]. Pre-service teachers' evaluation ability should be centred on the willingness to take risks and try new things, while cross-disciplinary project work is necessary for developing and sharing skillsets, as argued by Wrigley and Straker [39]. If there is a lack of risk propensity, pre-service teachers might have difficulties in assessing/perceiving design thinking deliverables [33].

Perceived design thinking ability in pre-service teachers might also be affected by feedback seeking and experimentation, which can be fostered by divergent thinking in the technology-enhanced interactive and collaborative learning environment of user-centred designs [48]. Communication, collaboration, and critical thinking skills might be helpful in divergent thinking and creativity to impose constraints on different idea generation techniques so as to enable thinking beyond the usual experiences and domains to overcome design fixation [9]. As argued by Butler and Roberto [9], carefully designed constraints can force team members or collaborators to use time and resource management together with a targeted selection of mind tools. Moreover, it is expected that pre-services teachers will frequently utilise self-directed learning to identify design and project management tasks, but they (especially the novices) might have difficulties in planning, implementing, monitoring, and fixing up strategies (reflection in action), particularly during early design phases, as argued by Lawanto et al. [33]. Design thinking skills developed in self-directed learning may provide mental habits as transformative learning outcomes for pre-service teachers, which will be useful for their creative problem-solving and innovation learning as a form of pedagogical change [12]. In turn, this will strengthen one's confidence in tackling difficult, complex, and global issues, as argued by Kijima et al. [13].

It could be that the effective implementation of design thinking as part of educational reforms for 21st century skills in teacher education might help both pre-service and in-service teachers to change their beliefs and practices, and to develop their ability to rethink the existing curriculum and implement an innovative one, including the content and pedagogy underpinning it, as stated by Haug and Mork [24].

1.2. Science and Technology Teacher Education in Slovenia

As seen in Figure 1, the Slovenian education system comprises pre-school, basic, secondary, and tertiary education. Primary education is delivered by public and private kindergartens, basic schools, basic schools with adapted education programmes, music schools, and educational institutions for children with special educational needs. Secondary education is delivered by secondary and upper secondary schools, which provide general or vocational technical education and secondary professional or technical education. Tertiary education, consisting of higher post-secondary vocational education and higher education, is provided by public and private institutions. Higher post-secondary vocational education is delivered by higher vocational colleges, while higher education is delivered by faculties, art academies, and independent higher education institutions [49]. Degree study programmes in higher education are classified into three cycles: first cycle (academic study programmes and professionally oriented study programmes), second cycle (study programmes leading to M.Sc.), and third cycle (study programmes leading to Ph.D.). Slovenia has four universities with 37 faculties, three art academies or professional colleges, and 10 single higher education institutions established as private institutions. In addition to teaching, higher education institutions also conduct research and offer artistic activities [50].

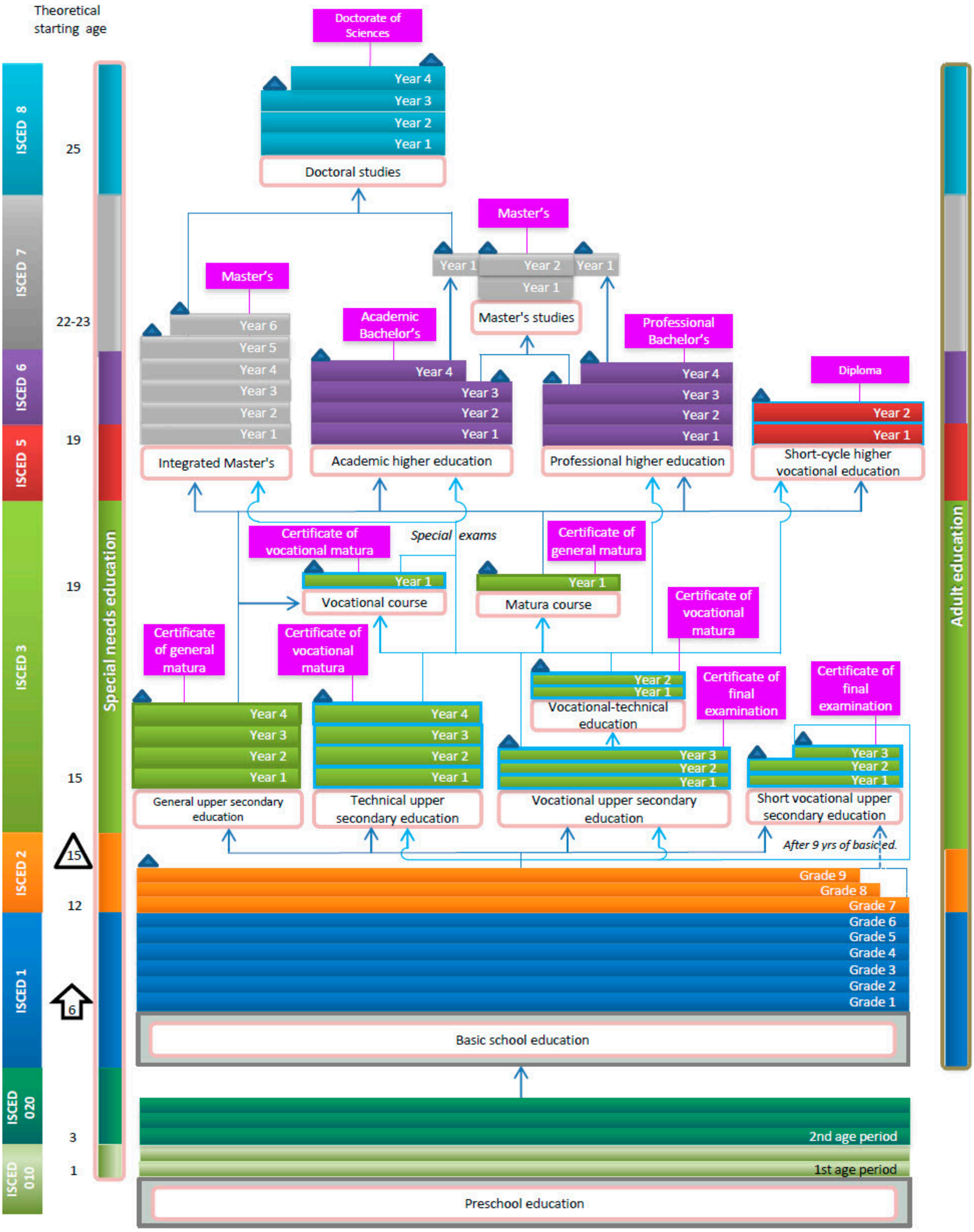

Figure 1. Structure of education system in the Republic of Slovenia [51].

Basic school teachers are mainly trained in Faculties of Education. The Primary Education study programme at the Faculty of Education University of Ljubljana qualifies teachers for teaching from the first to the fifth class of basic education. Completion of the first degree does not yet qualify the student for independent professional activity in the field of education. The fundamental aim of the programme is to train students for the continuation and completion of studies at the second level. A wide range of subject areas and additional furthering of knowledge through electives enable graduates of the first level to be employed and to work independently in other social activities and freelance professions. The Two-Subject Teacher study programme (Biology–Chemistry, Biology–Home Economics, Computer Science–Technical Education, Home Economics–Chemistry, Mathematics–Computer Science, Mathematics–Technical Education, Physics–Chemistry, Physics–Mathematics, Physics–Technical Education) at the Faculty of Education University of Ljubljana qualifies teachers for teaching specific subjects in the third educational cycle of basic education [52].

The graduates of the Two-Subject Teacher bachelor study programme gain fundamental professional knowledge from two subject areas and specialist didactic knowledge from the two subject areas, alongside practical pedagogical training and fundamental professional knowledge from the areas of pedagogy, psychology, philosophy, and sociology that is important for professions in education. The programme enables the continuation of study in the second Bologna cycle, resulting in a qualification for independent work in educational institutions in both of the selected subject areas [52].

1.3. Aims, Objectives and Research Questions of the Study

Design thinking appears to be an important aspect of STEM education for sustainable development. Thus, we need better ways of conceptualizing how to teach it, particularly with respect to designing pre-service teacher preparation programmes.

This study aims to map the relationships between self-directed learning and design thinking in pre-service science and technology teachers. Metacognitive knowledge and experience shape knowledge of behavioural principles in design thinking, but remain an underexplored topic in design cognition [25,53]. Flavell described metacognitive knowledge as "beliefs about what factors or variables act and interact in what way to affect the course and outcome of cognitive enterprises" that concerned "self, task, goals, and strategies" [54] (p. 2). Moreover, he also attributed metacognitive knowledge to prompting individuals to "select, evaluate, revise, and abandon cognitive tasks" while some metacognitive experiences are best described as items of metacognitive knowledge that have entered "consciousness". Moreover, studies on metacognitive design thinking in educational contexts from the pre-service science and technology teachers' perspective are rare.

This article explores the characteristics of and differences in design thinking and self-directed learning between pre-service science and technology teachers using reference groups of pre-service primary school teachers. The study also examines pre-service teachers' self-regulation in relation to design thinking skills in order to advance a theoretical understanding of design cognition and metacognition and to overcome challenges and problems teachers/educators face in adopting and implementing design thinking. Moreover, our study also aims to reveal constraints on translating cognition and metacognition into design thinking behaviour. Thus, results will provide feedback to designers, design educators, and pre-service teachers on their practices, while doing design and teaching design.

The study addressed the following research questions (RQs):

1. RQ1: What are the characteristics of self-directed learning in pre-service teachers?
2. RQ2: What are the characteristics of design thinking in pre-service teachers?
3. RQ3: What is the relationship between pre-service teachers' self-directed learning and their design thinking behaviour?
4. RQ4: Does self-directed learning influence the effect of the science and technology teacher education study programmes on design thinking?

The contribution of the present study is twofold. First, it aims at extending available insights on individual differences in design thinking within pre-service teachers' regulation behaviour. To further deepen current understandings of interindividual differences in the regulation behaviour of pre-service teachers in design practice, the study also investigates whether the identified self-regulation profiles predict and shape their understanding of the design thinking in and across different study programmes.

These innovative insights directly advance the current literature on interindividual variety in metacognitive regulation, and the mental processes and representations involved in designing [3,4,22,23,47], Second, by identifying key profiles of regulators during design thinking, the present study serves as an important starting point for designing customized metacognitive support, adapted to the characteristics and regulative needs that typify each regulation profile. As such, the study's findings might facilitate more personalised support in educational practice, which is likely to benefit design thinking participants' learning outcomes, and their attitudes towards design and design thinking [8,12,32].

2. Materials and Methods

2.1. Research Design

A quantitative approach was used in this empirical study. In particular, a survey was conducted to understand the self-directed learning in teacher education and to provide an underlying structure of design thinking for cultivating self-directed learners. Using survey data, we will describe and explore self-directed learning and design thinking in prospective teachers, explain and test the relationship between these two constructs, and test and evaluate how self-directed learning can be used for design thinking in different study programmes. This study is a two-level study. On the first level, Structural Equation Modelling (SEM) was used to find significant relationships between self-directed learning and design thinking, with self-directed learning subscales as ordinal independent variables, and design thinking subscales as dependent variables. On the second level, the study had one categorical independent variable, the teacher education study programme, which consisted of two discrete study programmes corresponding with our conditions—science and technology education—as well as a control condition where the study programme was focused on primary school teacher education. Participants were enrolled in one of three conditions as they were already engaged in the programme they chose at the beginning of the study; namely, pre-service two-subject science teachers, pre-service two-subject technology teachers, and pre-service primary school teachers. At the second level, the independent variable was manipulated by the study programme while the control condition presented a study programme where the science and technology subject matter was integrated. Two moderating variables, awareness and interpersonal skills, were derived from the first level as the strongest predictors in design thinking. The dependent variable was design thinking.

2.2. Sample

In Slovenia, only two universities, the University of Ljubljana and the University of Maribor, train science and technology teachers. In the academic year 2020/21, 271 prospective science and technology teachers were enrolled in undergraduate programmes at the University of Ljubljana, while 82 students were enrolled in undergraduate programmes for prospective science and technology teachers at the University of Maribor [52]. Prospective teachers for primary school teaching were selected as the reference group for the analysis.

Participants for this study (n = 219)—undergraduate students from pre-service teacher education at the University of Ljubljana, Slovenia, during the academic year 2020–2021—were recruited via an online classroom, Moodle, where a link to questionnaires was provided. A large majority of the participants were students in our courses. Therefore, we organized the survey during the online courses, while 63 students only received the link and took a survey independently. Of this group, only 15 participated in the survey, while the remaining 48 did not. Exclusion criteria included cases of missing data, those who completed the study in less than ten minutes, and those who failed an instructed response attention check. Two instructed-response attention check items were included in each questionnaire to detect inattentive respondents and improve data quality [55]. There were 158 participants who successfully completed the study and met all inclusion criteria. The sample included more female (n = 143, 90.50%) than male participants (n = 15, 9.50%). The distribution of students among different study programs for the second level of the study was as follows: 49 pre-service two-subject science teachers, e.g., Biology–Chemistry, Biology–Home Economics, Chemistry–Home Economics, Chemistry–Physics; 55 pre-service two-subject technology teachers, e.g., Technology–Mathematics and Technology–Physics; and 54 pre-service primary school teachers. For this article, a shortened annotation of students is as follows: pre-service science teachers, pre-service technology teachers, and pre-service primary school teachers.

This sample size was checked against the values produced by the GPower 3.1 analysis program [56]. A power analysis using GPower with the power (1-β) set at 0.95, $\alpha = 0.05$ indicated that a total sample of 89 participants would be needed to detect moderate effects ($F^2 = 0.15$) for the F-test using multiple regression with a maximum of five predictors in one level of the model.

We also reviewed the quality of the sample for the second stage of this study, in which a factorial analysis of variance was performed. A power analysis using GPower with the power (1-β) set at 0.80, $\alpha = 0.05$ indicated that a total sample of 158 participants would be needed to detect moderate effects ($F^2 = 0.25$) for the F-test using the factorial ANOVA with two degrees of freedom and three groups, including the reference group.

At the end of the educational work, the students were informed of the purpose of the study and given instructions on how to fill in the questionnaires. As this was a voluntary activity, students were free to withdraw from the study at any time and were not incentivised to provide responses.

The final sample of this study consisted of 158 students with a mean age of 21.34 years ($SD = 4.72$).

2.3. Instruments

2.3.1. Self-Directed Learning

A number of scales have been proposed to measure self-directed learning, as outlined by Litzinger et al. [57], Saks and Leijen [58], Ziegler [59], and Cadorin et al. [60]. However, considering the above characteristics of teacher education study programmes, Williamson's self-rating scale of self-directed learning seemed most appropriate to detect the skills required for pre-service teachers [61]. Moreover, in our previous studies [7,62], we had successfully used Williamson's questionnaire of self-directed learning, which was proven as valid and reliable for detecting the skills required for undergraduate pre-service teachers.

The questionnaire was used to survey students' perception of their ability for self-directed learning. The scale features 60 items in five subscales with 12 items each:

Awareness. Items relating to learners' understanding of the factors contributing to becoming self-directed in their learning process, such as thinking through tasks, applying prior experience, understanding how one's own strengths fit into the group dynamic, taking personal responsibility, maintaining self-motivation, identifying own learning needs and areas of deficit, updating learning resources, and setting own learning goals. One sample of these items in the self-assessment is: "I am responsible for identifying my areas of deficit."

Learning strategies. Items explaining the various strategies learners should adopt to become self-directed in their learning process, such as participating in group discussions using quality talk methods, peer coaching, role play, active learning, problem- and solution-driven approaches, technology-enhanced learning, and concept- and context-mapping. One sample of these items in the self-assessment is: "I find learning from case studies useful."

Learning activities. Items specifying the necessary learning activities learners should actively engage in to become self-directed in their learning process, such as rehearsal and revision of new lesson, highlighting important points when reading, effective use of ICT, task variation and divergence in team work, empathy, using a diversity of learning styles, relating knowledge with practice, using quality talk for answering and posting relevant questions, analysing and reflecting on new ideas, information, or learning experiences, and curiosity and proactivity. One sample of these items in the self-assessment is: "I keep annotated notes or a summary of all my ideas, reflections and new learning."

Evaluation. Items revealing learners' specific attributes in order to help monitor their learning activities, such as self-assessment, identification of areas for further development, monitoring learning progress, strengths, weaknesses, opportunities and threats analysis, learning from failure, peer evaluation, critical thinking, using different portfolios or learning management systems for monitoring learning progress, finding new learning challenges, and developing self-efficacy by observing peers and role models as benchmarks. One sample of these items in the self-assessment is: "I self-assess before I get feedback from instructors."

Interpersonal skills. Items relating to learners' skills in interpersonal relationships, which are a prerequisite to their becoming self-directed learners, such as contributing and supporting, monitoring and adapting, negotiating and decision-making, communicating, interacting, global citizen skills, and knowledge transfer and team learning. One sample of these items in the self-assessment is: "My interaction with others helps me to develop the insight to plan for further learning."

Williamson's original response scale was a 5-point Likert scale ranging from 5 (always) to 1 (never). The McDonald's omega tests show whether the scales are reliable, considering the acceptable values suggested by Pituch and Stevens [63], which should be greater than 0.70.

2.3.2. Design Thinking

The design thinking mindset explained in detail by Dosi et al. consists of 19 constructs with 71 items [64]. The original questionnaire has a 5-point Likert, scale while we used a 6-point Likert scale. We chose this scale because the ultimate purpose of the instrument was to track the development of metacognitive awareness for the purposes of either self-assessment or research. Moreover, since it has an even number of ratings on the scale, the 6-point Likert scale obligates respondents to choose the positive or negative end of the scale, resulting in better data. Furthermore, if at any point neutral is desired, then the "slightly agree" and "slightly disagree" can be averaged together [65–67].

The design thinking questionnaire's items are well-described in Dosi et al.'s study [64] and explained in ours [7]. The subscales/constructs involved in this study are: (1) Ambiguity and uncertainty tolerance, (2) Embracing risk, (3) Human centredness, (4) Empathy, (5) Mindfulness and awareness of the process, (6) Holistic view/consideration of the problem as a whole, (7) Problem reframing, (8) Team working, (9) Multi-/inter-/cross-disciplinary collaboration, (10) Openness to different perspectives/diversity, (11) Learning-orientation, (12) Experimentation or learning from mistakes or from failure, (13) Experiential intelligence/bias toward action, (14) Critical questioning, (15) Abductive thinking, (16) Envisioning new things, (17) Creative confidence, (18) Desire to make a difference and (19) Optimism towards having an impact.

2.4. Procedure and Data Analysis

Both questionnaires were sent as a link to the pre-service teachers' email addresses. Students gained access to the survey at https://1ka.arnes.si/a/569fc1be (accessed on 17 June 2022). Students participated in the study during online distance learning sessions at the end of the semester in May and June 2021 throughout a study day. A high response rate was achieved because students participating in the study spent time responding to the questionnaires during their pedagogical work. The questionnaires took 20–30 min to complete.

The data were analysed using SPSS Statistics, a software package commonly used for statistical analysis in the social sciences. To estimate ordinal reliability for Likert-type and ordinal item response, data collected in a single-administration McDonald's omega (ω) coefficient was used, as proposed by Komperda et al. [68] and Hayes and Coutts [69]. The McDonald's omega was calculated using Hayes' Omega macro for SPSS downloaded from www.afhayes.com (accessed on 17 June 2022). Moreover, we preferred the use of the McDonald's omega rather than the widely used Cronbach's alpha, since Cronbach's alpha assumes equal factor loadings and furthermore, the McDonald's omega can be used multidimensionally, too [69]. A descriptive analysis of the data was carried out to describe and summarise the characteristics of a sample, expressed by mean and standard deviations. Due to the violation of normality of the distributions and the nature of ordinal variables, the nonparametric Kruskal–Wallis test was used to detect statistically significant differences between the different groups of students. An ε^2 was used as a measure of effect size, as proposed by Tomczak and Tomczak [70].

Due to the relatively small sample size $n = 158$ and a lack of multivariate normality, a critical ratio of 98.09 was calculated, which is greater than the acceptable ratio of 1.96 [71]. The bootstrapping procedure in SEM was used to evaluate the path model. The IBM SPSS Amos (v.24) software program was used to fit SEM.

For a nuanced investigation into whether awareness and interpersonal skills would moderate the effect of pre-service science and technology teachers' education, overall trends were examined, with participants divided into 'higher' and 'lower' awareness and interpersonal skills groups, using a median split. After reviewing these mean trends, we conducted a 2×3 factorial analysis of variance (ANOVA), which included condition and awareness (interpersonal skills) (lower vs. higher) as independent variables and design thinking as the dependent variable. For a more nuanced investigation, we examined a full range of awareness (interpersonal skills) as a continuous variable. To facilitate a multiple regression analysis, we created dummy variables for pre-service teachers' education, where the primary school teacher education was the reference group.

2.5. Ethical Considerations

This study was conducted by the Department of Physics and Technology and Department of Biology, Chemistry and Home Economics, both at the Faculty of Education, University of Ljubljana. The students were informed about the purpose of this research, which aimed to improve teaching and learning in science and technology teacher education.

Participation in this study was completely voluntary, and students were given an informed consent form, which also explained the necessary precautions to protect the privacy of participating students. Students were also informed of the time it would take them to complete the survey and the importance of answering as they thought and not as they thought others expected them to. It was also highlighted that responses would be analysed and presented in groups, and that participants' identities would not be revealed under any circumstances. The participants showed understanding that they had the right to participate without compromising care, and that they had the right to not answer specific questions.

As we collected personal data, e.g., gender, age, year of study, and course of study, students were asked for informed consent to proceed with the survey. They were also given the opportunity to be informed about data collection, analysis, and storage details in this study, which complied with the General Data Protection Regulation (GDPR) of the University of Ljubljana. Upon enrolment, all students at the University of Ljubljana were informed that an authorised person at the University of Ljubljana is responsible for protecting personal data, monitoring and supervision counselling, and education, as per the GDPR.

3. Results

Prior to conducting further analyses, data were cleaned and coded, and each scale and the corresponding subscales were tested for internal consistency. As suggested by Pituch and Stevens [63], both scales demonstrated sufficient internal consistency for basic research via the McDonald's omega scores above 0.70. Means (*M*), standard deviations (*SD*), and bivariate correlations between variables can be found in Table 1. As shown in Table 1, the age and group of the students were not significantly correlated with self-directed learning and design thinking. Correlation between age and group indicates that pre-service primary school teachers were, on average, older than pre-service science and technology teachers.

Table 1. Means (*M*), standard deviations (*SD*), and Spearman's rho correlations.

Variable	*M*	*SD*	*1*	*2*	*3*	*4*
1. Age	21.34	4.72	1	0.19 *	0.07	0.00
2. Group				1	0.09	−0.06
3. Self-directed learning	3.87	0.49			1	0.71 **
4. Design thinking	4.02	0.54				1

Note. Group was coded as 1 for pre-service science teachers, 2 for pre-service technology teachers, and 3 for pre-service primary school teachers. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

3.1. Perceived Ability for Self-Directed Learning

Students' average scores across the study year and in total are shown in Table 2. Average scores are expressed with a mean and standard deviation. The questionnaire in the present research proved highly reliable, with McDonald's omega values of the constructs between 0.84 to 0.89. Therefore, the self-directed learning questionnaire proved to be a reliable and valid data collection instrument suitable for use in teacher education [63]. The McDonald's omega coefficient values, based on the sample of this study, are also shown in Table 2. The skewness and kurtosis values of the research constructs indicated that the data sets are not normally distributed, since some values exceed 1 (skewness) or 2 (kurtosis) as cut-off values proposed by Tabachnik and Fidel [72].

Table 2. Students' average scores with a measure of skewness (*S*) and kurtosis (*K*) on self-directed learning across the pre-service teachers' study programmes, and McDonald's omega values on self-directed learning questionnaire's subscales.

Subscale	**Pre-Service Science Teachers**				**Pre-Service Technology Teachers**				**Pre-Service Primary School Teachers**				**McDonald's Omega**
	M	*SD*	*S*	*K*	*M*	*SD*	*S*	*K*	*M*	*SD*	*S*	*K*	
Awareness	4.09	0.48	−0.19	−0.97	4.26	0.50	−1.82	4.43	4.15	0.48	−0.36	−0.08	0.85
Learning strategies	3.89	0.54	−0.13	−0.62	4.13	0.54	−1.22	1.07	3.99	0.47	−0.01	−0.78	0.84
Learning activities	3.61	0.62	0.04	−0.39	3.95	0.52	−0.28	−0.25	3.85	0.62	−0.59	0.44	0.85
Evaluation	3.91	0.58	−0.41	−0.03	4.00	0.54	−0.57	−0.44	3.93	0.65	−0.32	−0.45	0.88
Interpersonal skills	4.01	0.53	−0.44	0.27	4.20	0.58	−1.45	2.49	4.16	0.53	−0.27	0.33	0.89
Total score	3.90	0.46	−0.15	−0.19	4.11	0.47	−1.16	1.64	4.01	0.50	−0.08	−0.71	0.96

The differences observed between self-directed learning constructs are significant, with $p < 0.001$ (Friedman test: Chi-square value = 111.67; $p = 0.000$; weak effect size: Kendall's W = 0.18). It seems that the subscales of *Awareness* and *Interpersonal skills* were most developed while *Learning activities* was less developed. We confirmed this claim using a Wilcoxon rank test where the aforementioned more developed constructs significantly differed from all others ($p < 0.001$).

The test for normality by Shapiro–Wilk revealed a violation of the normality assumption across the study programmes ($p < 0.05$), suggesting the use of non-parametric tests.

To find the differences between the groups of students regarding their ability for self-directed learning across its subscales, a Kruskal–Wallis test was used with Dunn–Bonferroni post hoc tests. After conducting Bonferroni-adjusted significance tests for pairwise comparison, we found significant differences between pre-service technology and science teachers at subscales of (1) *Learning strategies* ($H = 22.802$, $p = 0.034$, moderate effect size $\varepsilon^2 = 0.15$), (2) *Learning activities* ($H = 26.243$, $p = 0.010$, relatively strong effect size $\varepsilon^2 = 0.17$), and at (3) *Interpersonal skills* ($H = 22.81.332$, $p = 0.033$, moderate effect size $\varepsilon^2 = 0.15$). No significant differences between different study programmes were found at the constructs of *Awareness* and *Evaluation* ($p > 0.05$).

3.2. Perceived Ability for Design Thinking

Students' design thinking ability was assessed on a 6-point Likert scale against 19 subscales of the questionnaire. Means, standard deviations, and differences in the subscales across the pedagogical and non-pedagogical students can be found in Table 3.

Table 3. Students' average scores with a measure of skewness (*S*) and kurtosis (*K*) on design thinking across the pre-service teachers' study programmes, and McDonald's omega values on design thinking questionnaire's subscales.

Subscale	Pre-Service Science Teachers				Pre-Service Technology Teachers				Pre-Service Primary School Teachers				McDonald's Omega
	M	*SD*	*S*	*K*	*M*	*SD*	*S*	*K*	*M*	*SD*	*S*	*K*	
Ambiguity and uncertainty tolerance	3.91	0.75	−0.43	−0.06	4.58	0.77	−0.34	−0.61	3.97	0.95	−0.03	−0.37	0.82
Embracing risk	3.89	1.30	−0.25	−1.02	4.34	0.93	−0.16	−0.82	3.79	1.06	−0.17	−0.08	0.83
Human-centredness	4.22	0.91	−0.39	−0.28	4.73	0.74	−0.01	−1.14	4.47	0.84	−0.11	−0.51	0.78
Empathy	4.96	0.81	−1.08	1.43	5.21	0.75	−0.71	−0.37	5.00	0.75	−0.44	−0.45	0.87
Mindfulness and awareness of process	4.51	0.72	0.14	−0.23	4.75	0.80	−0.65	0.02	4.46	0.72	0.30	0.04	0.80
Holistic view/considering the problem as a whole	4.69	0.86	−0.14	−0.93	4.91	0.80	−0.84	0.32	4.60	0.71	0.02	−0.28	0.84
Problem reframing	4.69	0.89	−0.65	0.09	4.78	0.86	−0.83	0.44	4.71	0.90	−0.23	−0.43	0.81
Team working	4.83	0.69	−0.66	0.23	5.05	0.71	−1.07	0.80	4.89	0.69	−0.17	−0.76	0.71
Multi-/inter-/cross-disciplinary collaboration	5.16	0.71	−0.52	−0.44	5.18	0.72	−1.15	1.23	5.06	0.71	−0.93	1.67	0.77
Openness to different perspectives/diversity	5.27	0.69	−0.85	−0.12	5.30	0.67	−1.39	1.87	5.21	0.66	−0.49	−0.67	0.82
Learning-oriented	5.13	0.70	−0.39	−1.18	5.32	0.59	−1.40	2.96	4.93	0.67	−0.38	0.51	0.87
Experimentation or learning from mistakes/failures	4.64	0.86	−0.80	0.19	4.91	0.67	−0.71	0.09	4.43	0.89	−0.04	−0.68	0.89
Experiential intelligence/Bias toward action	4.96	0.85	−1.11	1.57	5.24	0.72	−1.08	0.58	5.07	0.68	−0.81	0.64	0.82
Critical questioning	4.87	0.88	−0.91	1.27	5.16	0.62	−0.47	−0.63	4.45	0.89	0.06	−0.75	0.84
Abductivethinking	4.31	0.91	−0.58	0.88	4.66	0.73	−0.04	−0.82	4.41	0.91	−0.32	0.28	0.87
Envisioning new things	4.51	0.93	−0.17	−0.11	4.69	0.71	0.05	−0.78	4.52	0.77	0.09	−0.37	0.79
Creative confidence	4.66	0.93	−0.21	−0.49	5.07	0.82	−0.85	−0.17	4.47	0.82	0.01	−0.45	0.90
Desire to make a difference	4.88	0.78	−0.22	−0.81	4.93	0.76	−1.92	5.46	4.71	0.83	−0.48	0.25	0.79
Optimism to have an impact	4.68	0.92	−1.06	2.40	5.15	0.85	−1.38	2.25	4.72	0.92	−0.65	−0.19	0.83
Total score	4.71	0.55	−0.20	−0.35	4.98	0.55	−0.78	0.96	4.64	0.62	0.09	−0.23	0.97

The skewness and kurtosis values of the research constructs indicated that the data sets are not normally distributed, since some values exceed 1 (skewness) or 2 (kurtosis) as cut-off values proposed by Tabachnik and Fidel [72].

The questionnaire in the present research proved to be moderately to highly reliable, with McDonald's omega values of the constructs between 0.71 to 0.90. McDonald's omega coefficient values, based on the sample of this study, are also shown in Table 3. As for Cronbach's alpha, McDonald's omega values > 0.7 can be interpreted as an acceptable internal reliability [63].

The differences observed between design thinking constructs are significant, with $p < 0.001$ (Friedman test: Chi-square value = 638.18; $p = 0.000$; weak effect size: Kendall's W = 0.23). It seems that subscales of *Openness to different perspectives/diversity*, *Learning-oriented*, and *Multi-/inter-/cross-disciplinary collaboration* were the most developed while *Ambiguity and uncertainty tolerance*, *Embracing risk*, *Human-centredness*, and *Adductive thinking* were less developed. We confirmed this claim using a Wilcoxon rank test which revealed significant differences between subscales ($p < 0.001$).

The Shapiro–Wilk test for normality revealed a violation of normality assumption across the study programmes ($p < 0.05$), suggesting the use of non-parametric tests. Students' average scores on the subscale items were contrasted (using non-parametric tests) based on the study programme group as the differentiating factor. To find the differences between the groups of students with respect to their ability for design thinking across its subscales, a Kruskal–Wallis test was used with a Dunn–Bonferroni post hoc test. After conducting Bonferroni-adjusted significance tests for pairwise comparison, we found significant differences at subscales of (1) *Ambiguity and uncertainty tolerance* between pre-service technology teachers and pre-service science teachers (H = 34.368, p = 0.000, relatively strong effect size ε^2 = 0.22), and between pre-service technology teachers and pre-service primary school teachers (H = 31.216, p = 0.001, relatively strong effect size ε^2 = 0.20), (2) *Embracing risk* between pre-service technology teachers and pre-service primary school teachers (H = 22.057, p = 0.033, moderate effect size ε^2 = 0.14), (3) *Human centeredness* between pre-service technology teachers and pre-service science teachers (H = 24.776, p = 0.016, relatively strong effect size ε^2 = 0.16), (4) *Mindfulness and awareness of process* between pre-service technology teachers and pre-service primary school teachers (H = 21.474, p = 0.040, moderate effect size ε^2 = 0.13), (5) *Learning oriented* between pre-service technology teachers and pre-service primary school teachers (H = 27.565, p = 0.005, relatively strong effect size ε^2 = 0.18), (6) *Experimentation or learn from mistake/failure* between pre-service technology teachers and pre-service primary school teachers (H = 26.311, p = 0.008, relatively strong effect size ε^2 = 0.17), (7) *Critical questioning* between pre-service technology teachers and pre-service primary school teachers (H = 36.312, p = 0.000, relatively strong effect size ε^2 = 0.23) and between pre-service science teachers and pre-service primary school teachers (H = 22.672, p = 0.034, moderate effect size ε^2 = 0.15), (8) *Creative confidence* between pre-service technology teachers and pre-service primary school teachers (H = 31.595, p = 0.001, relatively strong effect size ε^2 = 0.20), and (9) *Optimism to have an impact* between pre-service technology teachers and pre-service primary school teachers (H = 23.269, p = 0.022, moderate effect size ε^2 = 0.15), and between pre-service technology teachers and pre-service science teachers (H = 26.007, p = 0.011, relatively strong effect size ε^2 = 0.17).

Considering the total score of design thinking, significant differences were found between pre-service technology teachers and pre-service primary school teachers (H = 27.624, p = 0.005, relatively strong effect size ε^2 = 0.18), and between pre-service technology teachers and pre-service science teachers (H = 22.057, p = 0.042, moderate effect size ε^2 = 0.14). Significant differences ($p < 0.05$) in design thinking between pre-service technology and science teachers were found in the following three constructs: *Ambiguity and uncertainty tolerance*, *Human centeredness*, and *Optimism to have an impact*.

3.3. SEM with the Bootstrapping Procedure

The current research utilized AMOS 24 to conduct an SEM to test and evaluate multivariate causal relationships. SEM is a combination of two statistical methods: confirmatory factor analysis (CFA) and path analysis [71,73]. CFA estimated the latent psychological traits (self-directed learning and design thinking) while path analysis aimed to find the causal relationship among variables of self-directed learning and design thinking by creating a path diagram. Five logical steps were utilised while conducting the SEM: model specification, identification, parameter estimation, model evaluation, and model modification [71,73]. It was hypothesised that students' self-directed learning may affect their design thinking in teacher education. We also hypothesized that constructs of self-directed learning as exogenous variable effects would be significantly correlated with both positive and negative outcomes. Moreover, some possible correlations are expected between design thinking variables, and these variables may also serve as mediators for self-directed learning variables. We also calculated the explained variances using R^2 from the model, where R^2 = 0.02 signifies a small impact, R^2 = 0.13 a medium effect size, and R^2 = 0.26 a large effect size [63].

In model development, we first constructed the initial model, which included five SDL subscales' scores as exogenous variables and 19 constructs of design thinking as endogenous variables. According to commonly used fit indices [74,75], we found a poor model fit. We observed a significant p value (0.000) in the Chi square test (526.04); the Chi square divided by its degrees of freedom was smaller than 5 (2.90). The goodness of fit index (GFI), comparative fit index (CFI) and Tucker–Lewis coefficient (TLI) values were not greater than 0.90 (0.75, 0.89 and 0.83, respectively); the root mean square error of approximation (RMSEA) and root mean square residual (RMR) were greater than 0.05 (0.11 and 0.13, respectively). The GFI, CFI and TLI indexes were also considered acceptable at the >0.90 level [76]. The probability level of the test of close fit (PCLOSE) was lower than 0.05 (0.00). These results indicated that the robust initial model did require improvement.

After several attenuation corrections we developed a model, and according to commonly used fit indices, we found a good model fit. We eliminated one construct of design thinking (*Embracing risk*) and applied some correlation paths between design thinking constructs. In the final model, with 18 constructs of design thinking, we observed a non-significant p value (0.11) in the Chi square test (198.37); the Chi square divided by its degrees of freedom was between values 1 and 5 (1.30) and met assessment guidelines by Hair et al. [77] for good fit. The GFI, CFI and TLI values were all greater than 0.90 (0.92, 0.99 and 0.98, respectively); the RMSEA was smaller than 0.05 (0.03) while the RMR was smaller than 0.05 (0.03). The PCLOSE was greater than 0.05 (0.86). The probability level of the test of close fit was also higher than a proposed threshold level of 0.50 for a good model fit [74,77]. These results indicated that the path model did need special attention due to small sample size (n = 158) and no multivariate normality (critical ratio was of 98.09 > 1.96). The basic method of model validation is to test a model with two or more random datasets from the same sample [78]. Therefore, the validation requires a large sample size or the bootstrapping procedure [78]. The procedure obtained 2000 usable bootstrap samples, which is sufficient for the bootstrapping procedure advised by Byrne [71], Chernick [79], and Streukens and Leroi-Werelds [80]. First, the adequacy of the entire hypothesized model, based on a transformation of the data so that the model fits the data exactly, was evaluated using the Bollen–Stine approach [74,81]. A Bollen–Stine bootstrap p value of <0.05 means that the hypothesized model should be rejected. In the present example, the p value was 0.71, indicating that the model tested via the bootstrapping procedure was not significantly different to the hypothesized model.

The relationships between self-directed learning and design thinking with statistically significant ($p < 0.05$) standardised path coefficients are presented in Figure 2. Only the direct influence of independent variables (self-directed learning) is shown while moderating influence of design thinking constructs are not the focus of this study.

As the path coefficients, standardised Beta (β) weights were used as shown in Figure 2, and they reflect strength and direction of change in predicting the dependent variable when the predictor changes. β weight ranges from +1—positively related to −1—negatively related [82].

The descriptive analysis of the dependent variable of design thinking revealed that students' ability for design-based learning has been perceived as above average, while the SEM analysis explains how predictor variables of self-directed learning can affect their behaviour in learning.

For the pre-service teachers, design thinking performance as a desired behaviour was well-supported in 18 out of 19 constructs, since active learning seems to be aligned well in the study programme, with all self-directed constructs predicting design thinking significantly ($p < 0.05$) in both directions, positive and negative.

The strongest positive predictor was found to be learning activities necessary for self-directed learning (β = 0.48), which strongly predicts students' *Ambiguity and uncertainty tolerance*, followed by awareness, which strongly predicts students' optimism to have an impact in learning (β = 0.38). *Interpersonal skills* (β = 0.34) predicts an ability for teamwork in active learning. A visual inspection of other path coefficients revealed that *Awareness* and *Interpersonal skills* might have a strong direct influence on design thinking. This will be investigated in the next section.

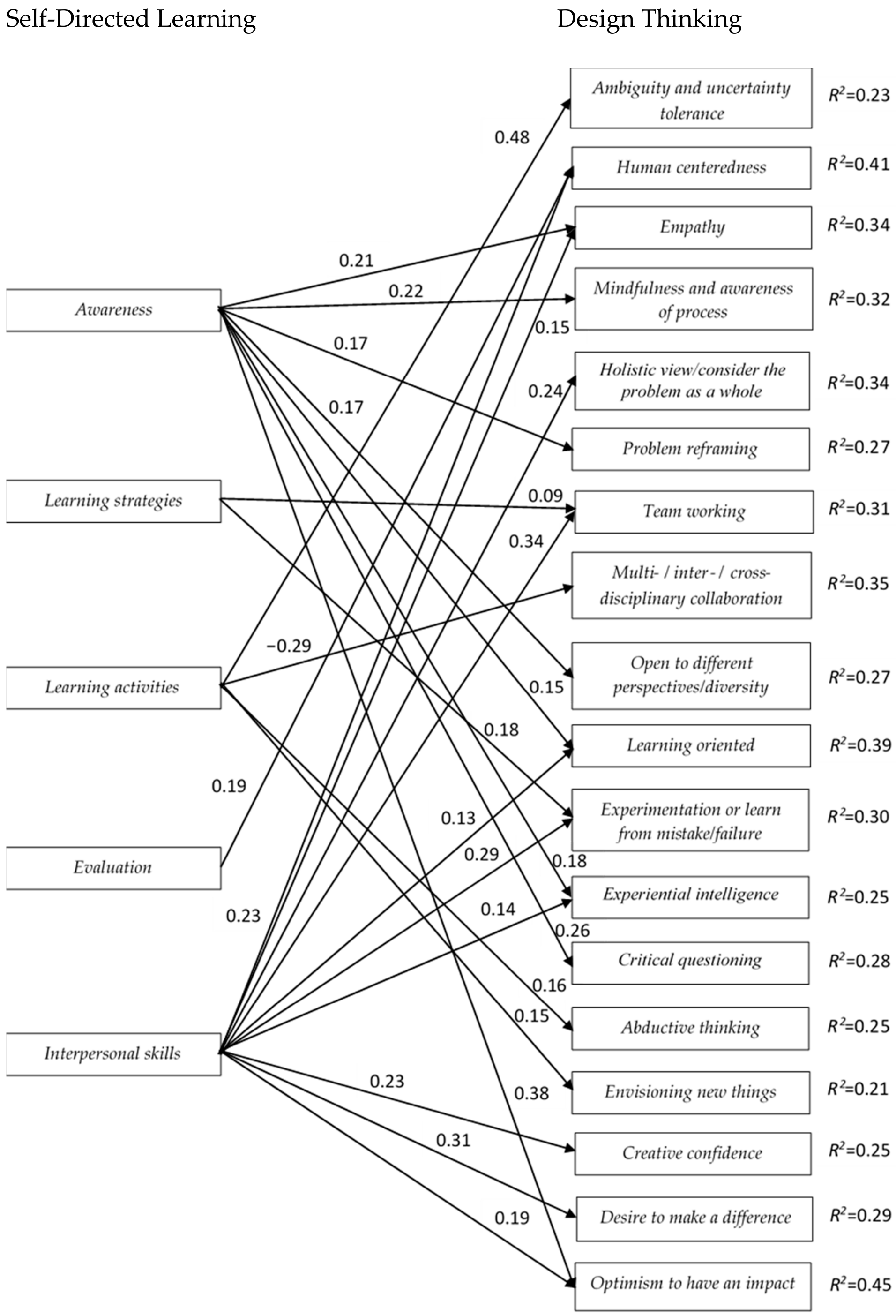

Figure 2. Relationships between self-directed learning and design thinking. Only direct influence of independent variables is shown.

Interestingly, the path model revealed an interesting pathway, namely that students' *Learning activities* negatively predicted their ability for multi-/inter-/cross-disciplinary collaboration (β = −0.29). It seems that highly competent self-directed pre-service teachers will find it difficult to collaborate with people outside of their own discipline or institution, and different perspectives from other disciplines make them uncomfortable. It seems that those learners like to spend time with peers or others only from teacher education backgrounds, to develop and conduct their own learning activities. Indeed, we confirmed the findings of Marquez-Garcia et al. [41] as they found that pre-service teachers shared experiences with others involved in education and school processes, e.g., peers, educators, teachers, and families.

As the weakest self-directed predictor in design thinking, a subscale of *Evaluation* was found, pointing to the lack of supervision activities for design thinking as suggested by Vossen et al. [8], or to the lack of pedagogical content knowledge and design experiences to differentiate psychological constructs of teaching that affect their design thinking deliverables, such as self-efficacy, the use of learning strategies, and motivation, as also argued by Duffin et al. [29].

3.4. Relationships between Self-Directed Learning, Design Thinking, and Pre-Service Science and Technology Teacher Education

This study's hypothesis predicted that self-directed learning would moderate the effect of pre-service science and technology teacher education on design thinking. From enabled visualisation of design thinking (see Figure 2) we first hypothesised that *Awareness* and *Interpersonal skills* as strong predictors might have a moderating effect on design thinking.

First, we conducted a median split of self-directed learning and design thinking to divide participants into 'higher' and 'lower' awareness and interpersonal skills groups. After this, we conducted a 2 × 3 factorial analysis of variance (ANOVA), which included condition (study programme) and awareness (lower vs. higher) as independent variables and design thinking as the dependent variable (Table 4).

Table 4. Design thinking by awareness (lower vs. higher) and different study programmes.

Source	Type III Sum of Squares	*Df*	Mean Square	*F*	Sig. *p*	Partial η^2
Corrected Model	16.73 [a]	5	3.34	13.32	0.000	0.30
Intercept	3373.81	1	3373.81	13,434.55	0.000	0.98
Group	0.90	2	0.45	1.79	0.169	0.03
Awareness	12.21	1	12.21	48.64	0.000	0.24
Group × Awareness	0.92	2	0.46	1.83	0.164	0.03
Error	38.17	152	0.25			
Total	3664.27	158				

Note: [a]. Adjusted R^2 = 0.35.

Our results indicated a significant main effect for awareness, F (1, 152) = 48.64, $p < 0.001$, while a non-significant interaction term was detected, F (2, 152) = 1.83, $p > 0.05$.

For a more nuanced investigation, we examined the full range of awareness as a continuous variable. To facilitate a multiple regression analysis, we created dummy variables for the study programme, with the pre-service primary school teacher study programme as the reference group. We conducted a multiple linear regression (Table 5), regressing design thinking onto awareness, dummy condition variables and interaction terms, which explained a significant 51% of the variance in design thinking, F (5, 152) = 31.71, $p < 0.001$.

Table 5. The interactive effect of awareness and pre-service science and technology teachers' study programmes on design thinking.

	Unstandardized Coefficients		*t*	Sig. *p*
	β	Std. Error β		
Constant	0.45	0.50	0.90	0.367
Pre-service science teachers	2.15	0.72	2.97	0.003
Pre-service technology teachers	1.01	0.69	1.45	0.147
Awareness	1.01	0.12	8.42	0.000
Pre-service science teachers × awareness	−0.49	0.17	−2.85	0.005
Pre-service technology teachers × awareness	−0.19	0.16	−1.14	0.253

Note. Adjusted R^2 = 0.51.

As detailed in Table 5, awareness, pre-service science teachers, and the interaction between the two were significant predictors in the model. Thus, our hypothesis was partially supported: Awareness moderated some but not all effects of pre-service teacher education on design thinking. As expected, the biggest differences among the conditions were at the high end of awareness. Pre-service science teachers high in awareness learning reacted with the least confidence about being capable of design thinking, whereas pre-service technology teachers appeared to react evenly at both ends of self-directed learning, lower and higher. It seems that pre-service science teachers, when they are highly aware and believe there is a low chance of success in the design thinking outcome, tend to think that the outcome is more influenced by external factors than their efforts, as also argued by Silvia and Duval [83].

The same procedure was followed for interpersonal skills. First, we conducted a 2 × 3 factorial analysis of variance (ANOVA), which included condition (study programme) and interpersonal skills (lower vs. higher) as independent variables and design thinking as the dependent variable (Table 6).

Table 6. Design thinking by interpersonal skills (lower vs. higher) and different study programmes.

Source	Type III Sum of Squares	*Df*	Mean Square	*F*	Sig. *p*	Partial η^2
Corrected Model	20.11 [a]	5	4.02	17.57	0.000	0.36
Intercept	3260.44	1	3260.44	14,244.92	0.000	0.98
Group	0.42	2	0.21	0.93	0.394	0.02
Interpersonal skills	16.36	1	16.36	71.48	0.000	0.32
Group × Interpersonal skills	0.22	2	0.11	0.48	0.616	0.01
Error	34.79	152	0.22			
Total	3664.27	158				

Note: [a]. Adjusted R^2 = 0.36.

Results indicated a significant main effect for interpersonal skills, F (1, 152) = 71.48, p = 0.000, while non-significant interaction term was detected, F (2, 152) = 0.48, $p > 0.05$.

We also conducted a multiple linear regression (Table 7), regressing design thinking onto interpersonal skills, dummy condition variables and interaction terms, which explained a significant 51% of the variance in transformative learning, F (5, 152) = 33.86, $p < 0.001$.

Table 7. The interactive effect of interpersonal skills and pre-service science and technology teachers' study programmes on design thinking.

	Unstandardized Coefficients		*t*	Sig. *p*
	β	Std. Error β		
Constant	0.95	0.47	2.14	0.035
Pre-service science teachers	1.42	0.68	2.22	0.027
Pre-service technology teachers	1.01	0.60	1.68	0.101
Interpersonal skills	0.88	0.11	8.33	0.000
Pre-service science teachers × Interpersonal skills	−0.31	0.15	−1.98	0.048
Pre-service technology teachers × Interpersonal skills	−0.11	0.15	−1.12	0.239

Note. Adjusted R^2 = 0.51.

As detailed in Table 7, interpersonal skills and interacting terms for pre-service science teachers were a significant predictor in the model. Thus, our hypothesis was partially supported: Interpersonal skills moderated some but not all effects of pre-service science teacher education on design thinking. As expected, the biggest differences among the conditions were at the high end of interpersonal skills. As depicted in Table 2, pre-service science teachers, especially those from the high ability end, have a lower level of interpersonal skills than pre-service technology teachers; thus, they cannot communicate well across disciplines and work with other people, which is very necessary for effective design thinking, as argued by Razzouk and Shute [35]. Perhaps we can also attribute this to the lack of experience in communication, establishing interactions, decision-making, knowledge transfer and teamwork, since pre-service science teachers were, on average, younger than their counterparts.

The same procedure was also followed with the subscale of *Learning strategies*, *learning activities* and *evaluation*, but no significant moderating effects on design thinking were detected ($p > 0.05$). According to the reference group, it seems that the aforementioned constructs are just a direct predictor of student design thinking, not the student's study major.

4. Discussion

Design thinking can be taught and implemented in a number of ways where several influencing factors can affect outcomes. Science and technology teacher education aims to stay competitive and cope with challenges from natural, social and economic environments that might affect delivery of the curriculum. These challenges and complicated problems need more attention, self-regulation in learning, active approaches where design thinking can be seen as an effective approach to deliver innovative ideas, and solutions for these problems. Moreover, design efforts should maximise potential benefits and minimise potential harm to the aforementioned environments, as argued by Ericson [2]. This study focuses on the meta-cognitive structure of pre-service science and technology teachers to probe their understanding of design thinking. By examining the circumstances under which the study programme reduces the individuals' confidence, they will be able to learn and apply design thinking in a study programme.

4.1. Pre-Service Teachers' Characteristics of Self-Directed Learning

Pre-service teachers' self-directed learning was assessed against five subscales. All self-directed processes were found to be above average (a mid-point of the scale is 3), but constructs were not evenly developed since self-directed learning is based on a dynamic conception of learning that takes place through different steps and intensities of learning, as confirmed by the assertions of [59,84]. It appears that pre-service teachers have two more developed constructs, *Awareness* and *Interpersonal skills*, which might contribute to transformative learning for pedagogical change, as argued by [85]. This change can be reflected in design thinking behaviour [19,20]. Moreover, it seems that pre-service teacher education at the University of Ljubljana engages more in reflective practice associated with experiential and other active student-centred learning methods to develop self-awareness, as also argued by Silvia and Duval [83].

Pre-service technology and science teachers differ significantly ($p < 0.05$) on subscales of *Learning activities*, *learning strategies* and *interpersonal skills* in favour of pre-service technology teachers. This points to a lack of experience, knowledge and skills in younger pre-service teachers (in average they were younger than their counterparts) needed to plan, implement, monitor and fix up strategy in learning, as confirmed by the findings of Lawanto et al. [33]. Interestingly, pre-service teachers' awareness of process and evaluation ability did not differ across the groups of students. It seems that pre-service teachers in all subjected study programmes were similarly aware of the weakness and strength of the topic with the learning outcomes, methods and tools of assessment of learning deliverables. It seems that upskilling in the aforementioned two constructs takes significant time, along with specific activities conducted in teacher education to utilise a student-centred method based on constructivism and social-cognitive theory towards transformative learning, as suggested by Mezirow [85].

4.2. Pre-Service Teachers' Characteristics of Design Thinking

Pre-service teachers' design thinking was assessed against 19 constructs and, as expected, significant differences were found between subscales ($p < 0.05$). Pre-service teachers engage in design thinking with little understanding of the problem from the customer's perspective, as confirmed by the findings of Mentzer et al. [6]. Moreover, they do not have a high tolerance of ambiguity, uncertainty and risk taking. More likely, when they engage in design thinking, they use design fixation and case-based design to generate a single solution analytically rather than comparing alternatives, as confirmed by the findings of Mentzer et al. [6]. Since they are very learning-oriented and open to diversity, it appears that pre-service teachers focus on problem solving (problem definition and reframing) when engaged in design thinking, but not so much on the use of solution-driven design thinking focused on the generation of several solutions, as suggested by Dorst [5], for effective critical evaluation of design solutions. Pre-service teachers are deeply engaged in different interactions and collaborations, since their active learning, practising and internship in different educational institutions rely on this. It seems that more embodied learning in technology education using different experiments, tools, machines, devices and ICT can boost design thinking in *ambiguity and uncertainty tolerance*, *embracing risk*, *human-centredness*, *mindfulness and awareness of process*, *experimentation or learn from mistake/failure*, *learning-oriented*, *critical questioning*, *creative confidence* and *optimism to have an impact*. Moreover, pre-service technology teachers outperformed their counterparts from primary school teacher education, while with pre-service science teachers they differed only in *ambiguity and uncertainty tolerance* and *human-centredness*. It seems that developing emotional and cognitive empathy as an ability to collect data for identifying and prioritising end users' different values and needs, along with accepting uncertainty and openness to risk, were critical issues in the development of design thinking in teacher education, as confirmed by the findings of Butler and Roberto [9], Henriksen et al. [11], Schweitzer et al. [21], and Retna [30]. *Empathy* can be a decisive element in shifting reasoning modes to conceive and qualify design proposals, since it requires recognition of the normative nature of design, strongly predicted by self-awareness and interpersonal skills to establish collaborators' positions, as confirmed by the findings of Rusmann and Ejsing-Duun [10]. Moreover, design thinking in pre-service teachers appears to need more support in metacognitive processes that control iteration as an important design process. To control iteration in pre-service teachers' design, some actions are proposed by Carlson et al. [25], such as focusing attention on key areas of the project, identifying project risks, and choosing iterative strategies to mitigate risks.

4.3. Relationship between Pre-Service Teachers' Self-Directed Learning and Their Design Thinking Behaviour

SEM was used to estimate relationships between pre-service teachers' self-directed learning and their design thinking behaviour, as depicted in Figure 2 where only direct effects were examined.

Pre-service teachers' design thinking is well-supported in self-directed learning, where 18 out of 19 constructs of design thinking showed a large proportion of explained variance ($R^2 = 0.21 - 0.45$). *Embracing risk* was a very important aspect in design thinking as it seemed to lack support in self-directed learning. Risk propensity seemed to be rather rooted in personality, differing across job types and with clear links to age and sex, as argued by Nicholson et al. [86]. The teaching profession, predominantly female teachers themselves, are not subjected to risk-taking in their professional careers [86], and pre-service teachers perceive the teaching profession and competencies by highlighting learning by feeling, belonging, placing action in a social perspective, and sharing experiences with others, as argued by Márquez-García et al. [41]. To cultivate risk-takers or bearers, teacher education must pay more attention to peer-based learning, blogging, massive open online courses, open discussion on previous failures and shortcomings, and other risk-taking modelling activities wherein students may be exposed to a wider audience, in virtual environments and with the educational use of ICT [86]. Teacher educators need to provide learners a flexible and responsive programme structure (learning objectives, learning strategies, relevant learning activities, evaluation and assessment methods), which should be responsive to individual learning needs, more dialogue/interactions and autonomy permitted/required by the teaching method and learners to decrease transactional distance and provide clear feedback without misunderstandings, as argued by Vossen et al. [8], Wengrowicz [87], and Larkin and Jamieson-Proctor [88]. Thus, a need for the development of both cognitive and affective structures is detected, since the willingness to bear risk seems to be a combination of emotional coolness, toughness, activity, and a tendency towards casualness about control and rules, as claimed by Nicholson et al. [86]. Nicholson et al. [86] also stated that the combination of personal disposition, skills, and interests leads risk adapters towards roles and organisations to enhance their risk preferences, pointing to the lack of a risk-taking culture in teacher education and school systems in general. This might be related to rigid educational systems with out-of-date curricula, which need a drastic rethink, not only for methods and strategies used, but also for refreshment and actualisation of the teaching and learning environment, content included [12]. It seems that active learning involved and used in teacher education needs complementary methods to develop creativity and intellectual risk, where mistakes cannot be penalised and willingness to fail can be encouraged, as suggested also by Henriksen et al. [12]. Yet, a rethink is needed on how to balance constraints and manage recourse distributions in trial-and-error learning for design thinking behaviour.

All other constructs of design thinking have strong support in self-directed learning, either as single or multiple predictors. It seems that accepting uncertainty in design can be largely developed through different learning activities in collaborative learning environments, using real-life contexts and more elaborate and deliberative reason strategies, such as analogising and mental simulations, as suggested by Ball and Christensen [53], while *human-centredness* can be affected by two self-directed subscales; *evaluation* and *interpersonal skills*. It seems monitoring and feedback sought together with reflection-in-action that guides intuitive behaviour in the context of real-world design [53] might bridge the gaps in self-regulation, especially in early phases of design, as also argued by Lawanto et al. [33]. Since *evaluation* was found to be a weak predictor in design thinking, namely only for student's human-centredness ability, it points to the lack of supervision or monitoring of skills in students to effectively supervise the entire design process, as confirmed by the findings of Vossen et al. [8]. It seems that science and technology pre-service teachers are focused on the content of subject matter and supervision of research and experimental projects, while pedagogy for supervising design thinking tasks is missing or irrelevant, as argued by Vossen et al. [8].

Experimentation or learn from mistake/failure as a part of bottom-up processing, which is much preferred in developing empathy and defining user needs, has strong support in learning strategies used in design thinking and interpersonal skills needed for effective collaboration, communication, decision-making, and leadership. Thus, we can avoid encoding failures which lead to intentional blindness and might appear at top-down processing, as argued by Butler and Roberto [9]. A key to design thinking might be seeking the unexpected, to find surprises that can lead to breakthroughs and novelties [9]. A higher level of awareness and interpersonal skills might help designers to avoid the initial problem by avoiding design fixation and analytical processes.

In user experience design, a necessity to overcome confirmation bias is revealed, since it leads to insights that are not well-grounded in users' experiences [9]. Overcoming this requires an increased awareness of the process and higher-level interpersonal skills to address emotional disconnection to find what customers expect from us as designers.

Pre-service teachers reported a high level of multi-/inter-/cross-disciplinary collaboration and openness to diversity but this fact has support in only one direct predictor, learning activities and awareness with the process, accordingly. Learning activities conducted in self-directed learning are counterproductive for effective collaboration with stakeholders beyond the educational system, as confirmed by the findings of Márquez-García et al. [41]. To turn this trend, reach stakeholders out of teacher education and school systems and improve design thinking ability, a course designer must provide more real-life transdisciplinary and contextualised content situated within different disciplines, not just teacher education [20], which has been suggested by Henriksen et al. [11], Wrigley and Straker [39], and Soleas [47]. Since collaboration is crucial in design thinking, some studies suggest introducing first transactional distance theory [87]. Pre-service teachers need to be encouraged to collaborate with other students to develop a multidisciplinary way of thinking and learning when facing different engineering design challenges, as argued by Margot and Kettler [89]. For effective design thinking, the physical and psychological separation between learners, the content and the teacher/educator, can be reduced by (1) fostering a communicative learning culture, (2) aligning the needs, expectations and goals of all learners, (3) providing self-paced learning resources, (4) setting manageable milestones which can help reignite learners' motivation, (5) providing prompt and personalised feedback, and (6) pairing self-assessments with resources for the improvement of weak areas [87]. Moreover, each learner can participate in collaborative learning and not be penalised for biased findings or incomplete results, which helps improve the learner's risk propensity, as argued by Nicholson et al. [86].

An increased awareness and well-developed interpersonal skills are a key factor in the self-directed learning of design thinking, since they have direct predicting values in several constructs of design thinking. Strong awareness might contribute positively to reflective practice, to control and monitor the situational actions, as argued by Kavousi et al. [23] and Lawanto et al. [33] and to control and balance the need for fast and slow design thinking, as confirmed by the findings of [20] which enables using sophisticated skills as proposed by Tikhonova and Kudinova [45] to connect practical intelligence, intuitive driven with creative intelligence and adductive thinking driven in activities with reflexive, reactive and reflective reason [20], together with well-developed interpersonal skills, such as problem-solving and decision-making, communication, conflict resolution and mediation, teamwork, emotional intelligence, negotiation, persuasion, and influencing skills. Pre-service teachers will vastly develop structures for conceptual design cognition using executive function, long-term memory, creativity, experiential intelligence, imagery processing, visual perception, and semantic processing, as also argued by Hay et al. [22], even to address persistent and complex problems in teaching and learning [32].

Since awareness and interpersonal skills in pre-service teachers predict a majority of constructs of design thinking and play an important role in developing both cognitive and affective structures crucial for effective design thinking, we discuss their potential inside different study programmes of teacher education in the following subchapter.

4.4. The Effect of Pre-Service Science and Technology Teacher Education Study Programmes on Design Thinking in Self-Directed Learning

This study also examines the circumstances under which the study programme reduces the confidence individuals have and whether they will be able to self-direct learning in a programme. Results suggest that the students' belief that they will be successful in design thinking depends on the study programme under certain circumstances, namely, when their awareness is high and the programme is science education. While our hypothesis expected that awareness moderates the relationship between the study programme and design thinking, the results did not follow a perfectly predictable pattern. It seems that when they are highly aware and believe there is a low chance of success in design thinking outcome, pre-service science teachers tend to think that the outcome is more influenced by external factors than their efforts, as confirmed by the assertions of Silvia and Duval [83]. Thus, more support is needed in design thinking, especially for sophisticated thinking and risk propensity in learning, also argued by Lawanto et al. [33].

We also investigated whether interpersonal skills would moderate the effects of teacher education study programmes on design thinking. Results suggest that the students' belief that they would be successful in design thinking depends on the study programme under certain circumstances, namely, when their level of interpersonal skills is high, and the programme is science education. High-ability pre-service science teachers in design thinking advance less according to the reference group of pre-service primary school teachers.

The results also suggest that for both low- and high-ability pre-service technology teachers, the subscales of *awareness* and *interpersonal skills* advance evenly in design thinking, according to the reference group. In average, pre-service technology teachers have higher scores in the aforementioned subscales than their counterparts. Perhaps, then, they had a more realistic view of the challenges associated with design thinking behaviour, as confirmed by the findings of Henriksen et al. [12], Scheer et al. [14], Retna [30] and Lawanto [33]. To foster pre-service science and technology teachers' design thinking ability through self-directed learning, we propose the introduction of a pedagogical activity called community of inquiry based on Dewey pragmatism and constructivism [90], where interpersonal skills might be improved [91] for a deeper conceptual understanding of science and technology phenomena and developing self-correction for reconstructing habits and behaviours through classroom dialogue as a collaborative learning community as suggested by Haug and Mork [24] and Nichols et al. [90]. Moreover, increased pre-service teachers' awareness and improved interpersonal skills might help them to reflect on what they have learned as part of their professional development, not only what they have done during active learning, which aligns with Haug and Mork [24] and Silvia and Duval [83]. It could be that well-developed empathy, risk-taking, self-direction, and social skills in pre-service teachers can also enhance their reflective capacity by exposing their ideas to sceptics and perceiving critical feedback as a gift and amplifier for design thinking, as argued by Butler and Roberto [9].

4.5. Limitations of the Study

The present study involved some deficits: (1) a lack of pedagogical knowledge and teaching experience in younger pre-service teachers might cause perception problems in some latent constructs, such as learning strategies used, monitoring and evaluation ability, since some research suggests that novice pre-service teachers do not distinguish between those psychological constructs while graduating pre-service teachers do make this differentiation, as confirmed by [29]. Thus, results of pre-service science teachers who were younger on average than their counterparts may be treated with caution. (2) A much larger and more diverse sample is needed to support the generalisation of results. Pre-service science and technology teachers should also be recruited from the second Slovenian university, which also trains future professionals in this field. Moreover, involving pre-service teachers on second level according to the Bologna study might contribute to a clearer picture and reveal new insights to support design thinking in teacher education. (3) In this study, only a sociological survey was conducted. A need is identified for qualitative data that includes the perceptions of educators on the topic examined in the study. (4) Since the subjective uncertainty in design is constantly fluctuating, as argued by [53], a longitudinal study or mapping over time is needed. (5) Research has not directly examined design thinking and self-directed learning, but rather respondents' perceptions of these constructs. Thus, direct observation and assessment of the constructs is needed for the future studies.

5. Conclusions

In this study, researchers explored interactions between self-directed learning and design thinking in pre-service science and technology teachers. The results indicate a strong possibility for the shaping of design thinking behaviour as an outcome of self-directed learning in teacher education.

The self-reported ability to undertake self-directed learning was found to be above average among prospective teachers, with most constructs varying across study programmes, while study awareness was found to be the strongest. The COVID-19 pandemic constraint could affect the development of self-directed learning activities, while on the other hand, prospective technology teachers, where technology-enhanced design thinking is most developed and used, rate their self-directed learning skills higher than their counterparts.

Self-assessed design thinking ability was also not uniformly developed across constructs and programmes of study, but all reported scores were well above average.

The study also yielded interesting results depicted in the developed path model, indicating the possibility of both accelerating and slowing down design thinking using self-directed learning strategies. This finding could be useful in making decisions about which approach or mode of design thinking to use and how to adjust its intensity toward surface or deep learning of the subject matter.

By exploring factors affecting design thinking, we provide deeper insight on how to shape the cognitive and affective structures needed for effective design thinking. Pre-service teachers engage in design thinking with little understanding of the problems and potential solutions from the perspective of the customer and other disciplines that interact in real life. Pre-service teachers are more likely to use design fixation and case-based design as approaches in order to solve problems analytically, while the sophisticated thinking needed to connect practical intelligence with higher-order thinking skills is rather lacking. A huge deficit was detected in risk propensity in pre-service teachers, also due to the nature of teacher education, with predominately female students and the school system in general, while a strong need to rethink the current curriculum in the sense of the actualisation and optimisation of content, methods, and outcomes is detected. Pre-service teachers' awareness of the learning process, and their interpersonal skills, might play a crucial role in learning design thinking. Task awareness, knowledge of cognitive strategies, self-awareness, reflective process control, and reflective process monitoring should be developed in pre-service teachers as a priority for effective design thinking, together with risk taking ability, the valuing of empathy and emotional intelligence, and an openness to diversity. The incorporation of user-centred design and divergent thinking enhanced by well-designed constraints in teacher education are recommended as ways to foster feedback seeking and experiential intelligence, while fixations in the design process can be decreased. Moreover, we also suggest using design thinking for the performance of task assessment, especially in solution-driven active learning tasks, while we can simultaneously overcome misunderstandings in conceptual learning and enhancing creativity when developing 21st century skills and competencies.

We also suggest the introduction of pedagogy for supervision design thinking projects already in the pre-service curriculum, when pre-service teachers will carry out research or design tasks by themselves through engagement moments such as habitus engagement, knowledgeability engagement, and data-analysis engagement.

We believe that incorporating the self-directed design process into teacher education is beneficial for refining pre-service teachers' cognitive structures and schematic processes in both design thinking and other active learning methods and approaches. Deep insights and a better comprehension of design thinking yielded by this study can be helpful in the development of (1) design tools to assist designers in their tasks, (2) didactical tools to support more effectively designed self-directed learning processes, and (3) research tools to improve the efficiency and effectiveness of design research.

However, further work should focus on exploring how to overcome the weaknesses of pre-service teachers' design thinking in embracing risk by including various kinds of technology-enhanced experiments to facilitate one's ability to recognise valuable opportunities, be sensitive towards failure, and carve out learning opportunities from tanked solutions.

Author Contributions: Conceptualization, S.A. and V.F.S.; methodology, S.A.; validation, S.A. and V.F.S.; formal analysis, S.A.; investigation, S.A. and V.F.S.; resources, S.A. and V.F.S.; data curation, S.A.; writing—original draft preparation, S.A. and V.F.S.; writing—review and editing, S.A. and V.F.S.; visualization, S.A. and V.F.S.; supervision, S.A. and V.F.S.; project administration, S.A. and V.F.S.; funding acquisition, S.A. and V.F.S. All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the financial support from the Slovenian Research Agency (related to project No. P5-0433).

Institutional Review Board Statement: The study was conducted in accordance with the ethical principles and integrity in research of the University of Ljubljana, Slovenia.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

Acknowledgments: The authors thank the pre-service teachers at the University of Ljubljana, Faculty of Education Ljubljana, Slovenia for their important contributions to this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dym, C.; Agogino, A.; Erics, O.; Frey, D.; Leifer, L. Engineering design thinking, teaching, and learning. *J. Eng. Educ.* **2005**, *94*, 103–120. [CrossRef]
2. Ericson, J.D. Mapping the Relationship between Critical Thinking and Design Thinking. *J. Knowl. Econ.* **2022**, *13*, 406–429. [CrossRef]
3. Goldschmidt, G. Design Thinking: A Method or a Gateway into Design Cognition? *She Ji J. Des. Econ. Innov.* **2017**, *3*, 107–112. [CrossRef]
4. Gero, J.; Milovanovic, J. A framework for studying design thinking through measuring designers' minds, bodies and brains. *Des. Sci.* **2020**, *6*, E19. [CrossRef]
5. Dorst, K. The core of design thinking and its application. *Des. Stud.* **2011**, *32*, 521–532. [CrossRef]
6. Mentzer, N.; Becker, K.; Sutton, M. Engineering design thinking: High school students' performance and knowledge. *J. Eng. Educ.* **2015**, *104*, 417–432. [CrossRef]
7. Avsec, S.; Jagiełło-Kowalczyk, M. Investigating possibilities of developing self-directed learning in architecture students using design thinking. *Sustainability* **2021**, *13*, 4369. [CrossRef]
8. Vossen, T.E.; Henze, I.; Rippe, R.C.A.; Van Driel, J.H.; De Vries, M.J. Attitudes of Secondary School STEM Teachers towards Supervising Research and Design Activities. *Res. Sci. Educ.* **2021**, *51*, 891–911. [CrossRef]
9. Butler, A.G.; Roberto, M.A. When cognition interferes with innovation: Overcoming cognitive obstacles to design thinking. *Res. Technol. Manag.* **2018**, *61*, 45–51. [CrossRef]
10. Rusmann, A.; Ejsing-Duun, S. When design thinking goes to school: A literature review of design competences for the K-12 level. *Int. J. Technol. Des. Educ.* **2021**. [CrossRef]
11. Henriksen, D.; Gretter, S.; Richardson, C. Design thinking and the practicing teacher: Addressing problems of practice in teacher education. *Teach. Educ.* **2018**, *31*, 209–229. [CrossRef]
12. Henriksen, D.; Richardson, C.; Mehta, R. Design thinking: A creative approach to educational problems of practice. *Think. Ski. Creat.* **2017**, *26*, 140–153. [CrossRef]
13. Kijima, R.; Yang-Yoshihara, M.; Maekawa, M.S. Using design thinking to cultivate the next generation of female STEAM thinkers. *Int. J. STEM Educ.* **2021**, *8*, 14. [CrossRef]
14. Scheer, A.; Noweski, C.; Meinel, C. Transforming constructivist learning into action: Design thinking in education. *Int. J. Technol. Des. Educ.* **2012**, *17*, 8–19. Available online: https://ojs.lboro.ac.uk/DATE/article/view/1758 (accessed on 28 July 2021).
15. Koh, J.H.L.; Chai, C.S.; Wong, B.; Hong, H.-Y. *Design Thinking for Education: Conceptions and Applications in Teaching and Learning*; Springer: Singapore, 2015.
16. Laurillard, D. Teaching as a Design Science. In *Building Pedagogical Patterns for Learning and Technology*; Routledge: New York, NY, USA, 2012.
17. Patterson, R.E.; Eggleston, R.G. Intuitive Cognition. *J. Cogn. Eng. Decis. Mak.* **2017**, *11*, 5–22. [CrossRef]
18. Krathwohl, D.R. A revision of Bloom's taxonomy: An overview. *Theory Pract.* **2002**, *41*, 213–217. [CrossRef]
19. Lin, K.Y.; Wu, Y.T.; Hsu, Y.T.; Williams, P.J. Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *Int. J. STEM Educ.* **2021**, *8*, 1. [CrossRef]
20. Kannengiesser, U.; Gero, J. Design thinking, fast and slow: A framework for Kahneman's dual-system theory in design. *Des. Sci.* **2019**, *5*, E10. [CrossRef]
21. Schweitzer, J.; Groeger, L.; Sobel, L. The Design thinking mindset: An assessment of what we know and what we see in practice. *J. Des. Bus. Soc.* **2016**, *2*, 71–94. [CrossRef]
22. Hay, L.; Duffy, A.; McTeague, C.; Pidgeon, L.; Vuletic, T.; Grealy, M. Towards a shared ontology: A generic classification of cognitive processes in conceptual design. *Des. Sci.* **2017**, *3*, E7. [CrossRef]
23. Kavousi, S.; Miller, P.A.; Alexander, P.A. Modeling metacognition in design thinking and design making. *Int. J. Technol. Des. Educ.* **2020**, *30*, 709–735. [CrossRef]
24. Haug, B.S.; Mork, S.M. Taking 21st century skills from vision to classroom: What teachers highlight as supportive professional development in the light of new demands from educational reforms. *Teach. Teach. Educ.* **2021**, *100*, 103286. [CrossRef]
25. Carlson, S.E.; Rees Lewis, D.G.; Maliakal, L.V.; Gerber, E.M.; Easterday, M.W. The design risks framework: Understanding metacognition for iteration. *Des. Stud.* **2020**, *70*, 100961. [CrossRef]

26. Crilly, N. Fixation and creativity in concept development: The attitudes and practices of expert designers. *Des. Stud.* **2015**, *38*, 54–91. [CrossRef]
27. Hochberg, E.D.; Desimone, L.M. Professional development in the accountability context: Building capacity to achieve standards. *Educ. Psychol.* **2010**, *45*, 89–106. [CrossRef]
28. Yang, R.; Porter, A.C.; Massey, C.M.; Merlino, J.F.; Desimone, L.M. Curriculum-based teacher professional development in middle school science: A comparison of training focused on cognitive science principles versus content knowledge. *J. Res. Sci. Teach.* **2020**, *57*, 536–566. [CrossRef]
29. Duffin, L.C.; French, B.F.; Patrick, H. The Teachers' Sense of Efficacy Scale: Confirming the factor structure with beginning pre-service teachers. *Teach. Teach. Educ.* **2012**, *28*, 827–834. [CrossRef]
30. Retna, K.S. Thinking about "design thinking": A study of teacher experiences. *Asia Pac. J. Educ.* **2016**, *36*, 5–19. [CrossRef]
31. Kimbell, L. Rethinking Design Thinking: Part I. *Des. Cult.* **2011**, *3*, 285–306. [CrossRef]
32. Richmond, G.; Cho, C.; Gallagher, H.A.; He, Y.; Bartell, T. Fast and Slow Thinking to Address Persistent and Complex Problems in Teaching and Learning. *J. Teach. Educ.* **2021**, *72*, 401–404. [CrossRef]
33. Lawanto, O.; Febrian, A.; Butler, D.; Mina, M. Self-Regulation Strategies in an Engineering Design Project. *Int. Educ. Stud.* **2019**, *12*, 133–152. [CrossRef]
34. Mezirow, J. Transformative learning as discourse. *J. Transform. Educ.* **2003**, *1*, 58–63. [CrossRef]
35. Razzouk, R.; Shute, V. What Is Design Thinking and Why Is It Important? *Rev. Educ. Res.* **2012**, *82*, 330–348. [CrossRef]
36. Higgins, E.T. Beyond pleasure and pain. *Am. Psychol.* **1997**, *52*, 1280–1300. [CrossRef] [PubMed]
37. Kröper, M.; Fay, D.; Lindberg, T.; Meinel, C. Interrelations between Motivation, Creativity and Emotions in Design Thinking Processes—An Empirical Study Based on Regulatory Focus Theory. In *Design Creativity 2010*; Taura, T., Nagai, Y., Eds.; Springer: London, UK, 2011; pp. 97–104. [CrossRef]
38. Higgins, E.T. Promotion and Prevention: Regulatory focus as a motivational principle. In *Advances in Experimental Social Psychology*; Academic Press: Cambridge, MA, USA, 1998; Volume 30, pp. 1–46. [CrossRef]
39. Wrigley, C.; Straker, K. Design thinking pedagogy: The educational design ladder. *Innov. Educ. Teach. Int.* **2017**, *54*, 374–385. [CrossRef]
40. Norton, P.; Hathaway, D. In search of a teacher education curriculum: Appropriating a design lens to solve problems of practice. *Educ. Technol.* **2015**, *55*, 3–14. Available online: https://www.jstor.org/stable/44430419 (accessed on 30 September 2021).
41. Márquez-García, M.J.; Kirsch, W.J.; Leite-Méndez, A.E. Learning and collaboration in pre-service teacher education: Narrative analysis in a service learning experience at Andalusian public schools. *Teach. Teach. Educ.* **2020**, *96*, 103187. [CrossRef]
42. Kirschner, P.A.; Sweller, J.; Clark, R.E. Why Minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educ. Psychol.* **2006**, *41*, 75–86. [CrossRef]
43. Plattner, H.; Meinel, C.; Leifer, L. *Design Thinking Research: Building Innovators*; Springer: Cham, Switzerland, 2016.
44. Hynes, M.M. Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. *Int. J. Technol. Des. Educ.* **2012**, *22*, 345–360. [CrossRef]
45. Tikhonova, E.; Kudinova, N. Sophisticated Thinking: Higher Order Thinking Skills. *J. Lang. Educ.* **2015**, *1*, 12–23. Available online: https://ssrn.com/abstract=3053546 (accessed on 30 September 2021). [CrossRef]
46. Brookfield, S.D. Self-Directed Learning. In *International Handbook of Education for the Changing World of Work*; Maclean, R., Wilson, D., Eds.; Springer: Dordrecht, The Netherlands, 2009; pp. 2615–2627.
47. Soleas, E. Integrating design thinking and metacognition: An accessible way to cultivate thinkers. *Ubiquitous Learn.* **2015**, *8*, 1–13. [CrossRef]
48. Coleman, E.; Shealy, T.; Grohs, J.; Godwin, A. Design thinking among first-year and senior engineering students: A cross-sectional, national study measuring perceived ability. *J. Eng. Educ.* **2020**, *109*, 72–87. [CrossRef]
49. Ministry of Education, Science and Sport of the Republic of Slovenia. Slovenian Education System and Slovenian Qualifications Framework. Available online: https://www.gov.si/en/topics/slovenski-solski-sistem-in-slovensko-ogrodje-kvalifikacij/ (accessed on 17 November 2021).
50. EuroEducation Net. The European Education Directory. Slovenia. Available online: https://www.euroeducation.net/prof/slnco.htm (accessed on 17 November 2021).
51. Education GPS, OECD. Slovenia: Overview of the Education System. Available online: https://gpseducation.oecd.org/CountryProfile?primaryCountry=SVN&treshold=10&topic=EO (accessed on 8 July 2022).
52. University of Ljubljana. Bachelor and Single-Cycle Master Degree Programmes—University of Ljubljana Faculty of Education. Available online: https://www.uni-lj.si/study/bachelor/pef/ (accessed on 17 November 2021).
53. Ball, L.J.; Christensen, B.T. Advancing an understanding of design cognition and design metacognition: Progress and prospects. *Des. Stud.* **2019**, *65*, 35–59. [CrossRef]
54. Flavell, J.H. Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *Am. Psychol.* **1979**, *34*, 906–911. [CrossRef]
55. Meade, A.W.; Craig, S.B. Identifying careless responses in survey data. *Psychol. Methods* **2012**, *17*, 437–455. [CrossRef] [PubMed]
56. Faul, F.; Erdfelder, E.; Buchner, A.; Lang, A.G. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behav. Res. Methods* **2009**, *41*, 1149–1160. [CrossRef]

57. Litzinger, J.C.; Wise, T.A.; Lee, S.H. Self-directed learning readiness among engineering undergraduate students. *J. Eng. Educ.* **2005**, *94*, 215–221. [CrossRef]
58. Saks, K.; Leijen, Ä. Distinguishing self-directed and self-regulated learning and measuring them in the e-learning context. *Procedia Soc. Behav. Sci.* **2014**, *112*, 190–198. [CrossRef]
59. Ziegler, A.; Stoeger, H.; Vialle, W.; Wimmer, B. Diagnosis of self-regulated learning profiles. *Australas. J. Gift. Educ.* **2012**, *21*, 62–74. Available online: https://search.informit.org/doi/10.3316/aeipt.198175 (accessed on 17 June 2022).
60. Cadorin, L.; Suter, N.; Saiani, S.; Williamson, N.S.; Palese, A. Self-rating scale of self-directed learning (SRSSDL): Preliminary results from the Italian validation process. *J. Res. Nurs.* **2011**, *16*, 363–373. [CrossRef]
61. Williamson, S.N. Development of a self-rating scale of self-directed learning. *Nurse Res.* **2007**, *14*, 66–83. [CrossRef] [PubMed]
62. Avsec, S.; Ferk Savec, V. Pre-Service Teachers' Perceptions of, and Experiences with, Technology-Enhanced Transformative Learning towards Education for Sustainable Development. *Sustainability* **2021**, *13*, 10443. [CrossRef]
63. Pituch, K.A.; Stevens, J.P. *Applied Multivariate Statistics for the Social Sciences*; Routledge: New York, NY, USA, 2015.
64. Dosi, C.; Rosati, F.; Vignoli, M. Measuring design thinking mindset. In *Design 2018, Proceedings of the 15th International Design Conference, Dubrovnik, Croatia, 21–24 May 2018*; Marjanović, D., Štorga, M., Škec, S., Bojčetić, N., Pavković, N., Eds.; The Design Society: Dubrovnik, Croatia, 2018; pp. 1991–2002. [CrossRef]
65. Brown, S. *Likert Scale Examples for Surveys*; Iowa State University Extension: Ames, IA, USA, 2010.
66. Chomeya, R. Quality of Psychology Test between Likert Scale 5 and 6 Points. *J. Soc. Sci.* **2010**, *6*, 399–403. [CrossRef]
67. Chang, L.A. Psychometric Evaluation of 4-Point and 6-Point Likert-Type Scales in Relation to Reliability and Validity. *Appl. Psychol. Meas.* **1994**, *18*, 205–215. Available online: https://conservancy.umn.edu/bitstream/handle/11299/117059/v18n3p205.pdf?sequence=1&isAllowed=y (accessed on 22 September 2021). [CrossRef]
68. Komperda, R.; Pentecost, T.C.; Barbera, J. Moving beyond Alpha: A Primer on Alternative Sources of Single-Administration Reliability Evidence for Quantitative Chemistry Education Research. *J. Chem. Educ.* **2018**, *95*, 1477–1491. [CrossRef]
69. Hayes, A.F.; Coutts, J.J. Use Omega Rather than Cronbach's Alpha for Estimating Reliability. But . . . . *Commun. Methods Meas.* **2020**, *14*, 1–24. [CrossRef]
70. Tomczak, A.; Tomczak, E. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. *Trends Sport Sci.* **2014**, *1*, 19–25.
71. Byrne, B.M. *Structural Equation Modeling with AMOS: Basic Concepts, Applications, and Programming*, 3rd ed.; Routledge: New York, NY, USA, 2016.
72. Tabachnick, B.G.; Fidell, L.S. *Using Multivariate Statistics*, 7th ed.; Pearson: Boston, MA, USA, 2019.
73. Kline, R.B. *Principles and Practice of Structural Equation Modeling*, 4th ed.; The Guilford Press: New York, NY, USA, 2015.
74. Blunch, N. *Introduction to Structural Equation Modeling Using SPSS and AMOS*, 2nd ed.; Sage Publications: London, UK, 2013.
75. Schermelleh-Engel, K.; Moosbrugger, H.; Müller, H. Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods Psychol. Res.* **2003**, *8*, 23–74.
76. Hu, L.; Bentler, P.M. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Struct. Equ. Model. Multidiscip. J.* **1999**, *6*, 1–55. [CrossRef]
77. Hair, J.; Black, B.; Babin, B.; Anderson, R.E.; Tatham, R.L. *Multivariate Data Analysis*, 7th ed.; Prentice Hall: Englewood Cliffs, NJ, USA, 2009.
78. Fan, Y.; Chen, J.; Shirkey, G.; Ranjeet, J.; Wu, S.R.; Park, H.; Shao, C. Applications of structural equation modeling (SEM) in ecological studies: An updated review. *Ecol. Process.* **2016**, *5*, 19. [CrossRef]
79. Chernick, M.R. *Bootstrap Methods: A Guide for Practitioners and Researchers*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2008.
80. Streukens, S.; Leroi-Werelds, S. Bootstrapping and PLS-SEM: A step-by-step guide to get more out of your bootstrap results. *Eur. Manag. J.* **2016**, *34*, 618–632. [CrossRef]
81. Bollen, K.A.; Stine, R.A. Bootstrapping Goodness-of-Fit Measures in Structural Equation Modeling. In *Testing Structural Equation Models*; Bollen, K.A., Long, J.S., Eds.; Sage: Newbury Park, CA, USA, 1993; pp. 111–135.
82. Cohen, J.; Cohen, P.; West, S.G.; Aiken, L.S. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, 3rd ed.; Routledge: New York, NY, USA, 2003; pp. 32–35.
83. Silvia, P.J.; Duval, T.S. Objective Self-Awareness Theory: Recent Progress and Enduring Problems. *Pers. Soc. Psychol. Rev.* **2001**, *5*, 230–241. [CrossRef]
84. Zimmerman, B.J. Attaining self-regulation: A social cognitive perspective. In *Handbook of Self-Regulation*; Boekaerts, M., Pintrich, P.R., Zeidner, M., Eds.; Academic Press: San Diego, CA, USA, 2005; pp. 13–39.
85. Mezirow, J. *Learning as Transformation: Critical Perspectives on a Theory in Progress*; Jossey-Bass Publishers: San Francisco, CA, USA, 2000. Available online: https://eric.ed.gov/?id=ED448301 (accessed on 22 July 2021).
86. Nicholson, N.; Soane, E.; Fenton-O'Creevy, M.; Willman, P. Personality and domain-specific risk taking. *J. Risk Res.* **2005**, *8*, 157–176. [CrossRef]
87. Wengrowicz, N. Teachers pedagogical change mechanism–Pattern of structural relations between teachers' pedagogical characteristics and teachers' perceptions of transactional distance (TTD) in different teaching environments. *Comput. Educ.* **2014**, *76*, 190–198. [CrossRef]

88. Larkin, K.; Jamieson-Proctor, R. Using transactional distance theory to redesign an online mathematics education course for pre-service primary teachers. *Math. Teach. Educ. Dev.* **2015**, *17*, 44–61. Available online: https://files.eric.ed.gov/fulltext/EJ1078418.pdf (accessed on 22 September 2021).
89. Margot, K.C.; Kettler, T. Teachers' perception of STEM integration and education: A systematic literature review. *Int. J. STEM Educ.* **2019**, *6*, 2. [CrossRef]
90. Nichols, K.; Musofer, R.; Fynes-Clinton, L.; Blundell, R. Design thinking and inquiry behaviours are co-constituted in a community of inquiry middle years' science classroom context: Empirical evidence for design thinking and pragmatist inquiry interconnections. *Int. J. Technol. Des. Educ.* **2021**. [CrossRef]
91. Nichols, K.; Burgh, G.; Kennedy, C. Comparing two inquiry professional development interventions in science on primary students' questioning and other inquiry behaviours. *Res. Sci. Educ.* **2017**, *47*, 1–24. [CrossRef]