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The TEK Design Principles: Integrating Neuroscience and Learning Environment Research

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Abstract: People engage in learning in various settings and environments. This involves learning in a formal learning environment like a classroom and less formal environments such as museums and online. Interest is one of the key motivational theories and plays an important role in learning, as it can not only initiate and propel individuals to pursue an area of knowledge but also motivate them to maintain this pursuit in the long term. There has been a lack of research in the field of the design of learning spaces to support student-initiated knowledge generation. Coupled with the emerging area of neuroscience and education, this paper aims to synthesise neuroscience research with aspects of learning design to facilitate learning and interest development within a high school learning context. The Task, Environment and Knowledge Creation (TEK) design principles are proposed. Implications of the design principles are discussed.

Keywords: interest; motivation; neuroscience education; learning environment

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1. Introduction

People engage in learning in various settings and environments. A formal learning environment, such as a typical classroom setting, can be described as the active interaction between a learner and teacher or with other learners [1]. However, formal education environments are not the only places for learning. People also engage in learning in less formal environments such as museums, reading books and even through interactions with their peers or family [2]. These interactions are not restricted to just formal learning activities but also encompass interactions which facilitate the development of motivation, engagement and interest in learning.

Interest is one of the key motivational theories and plays an important role in learning, as it can not only initiate and propel individuals to pursue an area of knowledge [3] but also motivate them to maintain this pursuit [4]. The extant literature has established that interest is the product of the characteristics of individuals as well as the environment [5]. However, many studies have been focused on interest from a psychological perspective, with limited studies being undertaken on the influence of the external learning environment on interest development [6]. It has also been acknowledged by Temple [7] that there is a lack of research in the field of the design of learning spaces to support student-initiated knowledge generation. Furthermore, there is also a dearth in the research being conducted on the impact of the learning environment on learning within a high school context, with most of the current literature being based in Higher Education settings [8–10].

Coupled with the emerging area of neuroscience and education, this paper aims to unpack and integrate neuroscience research with aspects of learning design to facilitate learning and interest development within a high school learning context. This paper therefore aims to answer the research question 'What are neuroscience-informed learning environment design principles that facilitate learning and interest development in a high school context?'

2. Literature Review

2.1. Interest Development

From birth, children possess an inherent sense of curiosity to explore and manipulate their surrounding environments and to seek out objects that they find 'interesting' [11]. It is therefore natural that the process of acquiring knowledge and developing aptitude in a particular subject of interest is something enjoyable. Interest is widely recognised as an important motivational component crucial to learning [5], and is not simply restricted to its common use to describe something as enjoyable or fun. It is a multi-layered developmental process, and for the purpose of this paper, will be defined according to Renninger and Hidi's [5] definition, which states that interest is the product of the interplay between person and environment and includes cognitive components such as knowledge, as well as affective components such as enjoyment and excitement. One important component of interest, however, is that it is content-specific and instils a (potentially enduring) desire to reengage with the content.

Within education research, there has been a fundamental division of interest into two specific types: situational interest and individual interest [12]. Situational interest is triggered by specific stimuli from the environment and occurs at the moment of engagement. The triggering of interest may occur through novelty, choice, social involvement and even learning [13]. On the other hand, individual interest is a more enduring form of interest with a desire to reengage with the specific content. Based on the then-existing literature, Hidi and Renninger [12] developed the now frequently cited four-phase model of interest development, which suggests that interest develops through four stages, from earlier (less developed) phases to later (more developed) phases.

The first phase (triggered situational interest) arises primarily from affordances of the environment, which cause attention to be 'triggered' and are usually related to strong affective (either positive or negative) experiences. These triggers for interest typically involve the actual content matter of the topic, enabling the learner to make connections to content that lead to further information search [14]. Upon frequent reengagement with the content, interest progresses to the second phase of development—maintained situational interest. Interest at this stage is not solely dependent on the environment but can be sustained through activities learners find personally meaningful [4]. During this phase, feelings toward the content tend to be positive, and with the continued growth of knowledge and value for the content paired with continued encouragement and engagement, interest will progress to emerging individual interest [5,14]. In the third phase of interest development, learners begin to independently reengage with content and seek out additional information on the content matter, leading to a further deepening of the content knowledge. They may also become reflective about the content and, in the process, generate their own questions about the content [5]. This phase is categorised by generally positive affect and can further develop through continued support and encouragement. The continued development of interest will lead to a well-developed interest, where learners independently reengage through the search for additional information, accompanied by positive emotions, leading to this form of interest being mainly self-generated [14]. Learners at this phase have increased stored knowledge and value, might not need external support and are able to persist in the face of challenges [5].

However, interest needs to be sustained through frequency and depth of engagement; if not, it may remain dormant, regress to a previous phase or vanish completely [5,15]. It is therefore important for learners to be able to easily access support and additional opportunities to engage with the subject at a deeper level in order to facilitate their interest development.

2.2. The Power of Interest

Interest is able to produce remarkable results regarding learning. The development of interest is typically antecedent to increases in attention, sustains engagement, develops positive affect and consolidates understanding [14,16]. Interest has also been found to aid learners with low conscientiousness to purposefully engage with the content [17]. Another study also suggested that interest in a science class was able to predict an increase in class engagement, including attention, participation, effort and the use of cognitive strategies, which maximised the overall learning experience [18], eventually guiding their future pathways such as which courses to take in the future [19].

Interest is therefore not just relevant during a child's schooling years, but it has far-reaching impacts far beyond school, to the extent of influencing their choice of study in college and eventually even their career pathways, possibly charting the course for the rest of their lives. A better understanding of how students interact with learning activities can better illuminate our understanding of how interest is triggered and provide educators with more effectively designed learning environments that cater to students' learning needs [20]. For the aforementioned reasons, it is imperative for educators and researchers alike to have a better grasp of this phenomenon of interest in order to tap into its power to influence and inspire learners through the learning environment.

2.3. Educational Neuroscience

Educational research has historically been inundated with criticisms by the wider community, and even among its primary audience of education practitioners and administrators [21]. This is likely due to the fact that educational research is typically qualitative in nature, with limitations in its generalisability. It may therefore be perceived to be largely subjective and influenced by individual choice and beliefs, which researchers have argued may be a hindrance to the systematic development of its knowledge base [22]. In parallel, there has also been considerable development in the research of neurophysiological and cognitive mechanisms of learning [23]. The years 1990 to 2000 have been declared as the 'Decade of the Brain' due to neuroscience research obtaining significant attention in the United States of America [24]. The integration of more quantitative neuroscientific measures within education research may therefore be able to address the alleged criticisms of subjectivity and a lack of methodological rigour [25].

2.4. Neuroscience-Informed Principles of Learning

Goswami [26] has conducted numerous empirical studies focused on studying learning from a cognitive neuroscience perspective, with significant work in neuroscience and education. Her extensive research has distilled six neuroscience-informed principles of learning which are applicable to education.

The first principle states that learning is incremental and experience-based. In a similar vein to constructivism [27], learning is believed to occur when children go through different experiences over the course of life and learning. New fibre connections within the brain are formed during exposure to new stimuli, and it is through these connections that the brain encodes every experience, leading to the formation of networks which form cognitive structures such as language [26].

Second, learning is multi-sensory. As learning encompasses multiple senses, it will be represented across several neural networks which connect numerous neural structures together. What this means is that learning is therefore made accessible through a number of modalities [26]. A study conducted by James [28] found that preschool children who learnt letters from multi-sensory stimuli such as by looking (visual), writing (kinaesthetic) and naming letters (auditory) developed fibre connections between the visual and motor systems in the brain. This study provides further evidence on the interconnectedness of different neural networks within the brain. This would also mean that students who learn via multiple senses will be able to better reinforce their learning, as when learning occurs through multiple senses, it will be represented across a greater number of neural networks, which connects to a greater number of neural structures, making it accessible by a greater number of modalities.

Third, brain mechanisms of learning extract structure from input. As the learner is increasingly exposed to a wider range of experiences, the brain may experience a specific sensory stimulus multiple times. Through this process, the brain is able to distil common elements of these experiences, form correlations and develop causal relations [26]. It is also through the combination of direct knowledge transfer and self-exploration that teachers are able to help students extract principles from inputs [29].

Fourth, learning is social. Studies have found that the mammalian brain has evolved to thrive in social environments [26]. A study concluded that the mirror neuron system in humans was responsive to a person performing an action, but not when a robot performed the same action [30]. This is similar to social constructivist theory, which emphasises the effectiveness of learning in an external social environment.

Fifth, cortical learning can be modulated by evolutionarily older systems. This refers to the integration of emotional (earlier developed systems) and cognitive processes in the brain. This is evidenced by other research showing that when learners are engaged in an activity that is personally meaningful or relatable, the default mode network of the brain which is related to attention and conceptual understanding becomes activated [31].

Lastly, learning shows life-long plasticity and compensation. Neuroplasticity is the process whereby the human brain develops and changes over time in response to the external environment [32]. For instance, fiber connections in the brain are constantly being formed to accommodate new knowledge and experiences throughout adulthood [26]. In an educational context, this would mean that it is never too late to learn, which also highlights the importance of lifelong learning.

These six principles of learning are closely aligned with the social constructivist [33] theories of learning and have yet to be integrated into design principles of learning environments within the extant research literature. This paper will therefore offer a novel, neuroscientific perspective on design principles for facilitating interest and engagement.

2.5. Learning Environments

Social constructivist theories of learning have emphasised the importance of learners' own knowledge creation through exploration and social interaction [33]. From a social constructivist perspective, learning reaffirms the social experiences of learners, enabling them to assimilate and further develop whatever knowledge they possess [34]. Two key factors for facilitating social constructivist learning have been highlighted by Miyake and Kirschner [35]. First, there is the provision of learning spaces where more collaborative and social forms of learning are encouraged—for instance, through a flexible layout and furniture arrangement. By doing so, it can lead to a more student-centric learning environment, which has been found to foster intrinsic motivation [35], facilitate the development of positive relationships between learners [36] and even create positive perceptions of the learning environment [37]. Second, there is the provision of technology that facilitates personalised learning for each individual learner. The use of these two tenets has brought about positive findings in a recent study which showed improved consciousness among teachers regarding a skills-focused curriculum, affording the exploration of the learning space for meaningful ways to best engage learners [38].

Carvalho and Goodyear [2] described learning environments as the sociocultural settings and physical (or digital) settings in which learners perform various tasks. They also emphasised that learners' activities are situated in physically, epistemically and socially in their Activity-Centred Analysis and Design (ACAD) framework (Figure 1), which highlights how learning can be affected by its physical, social and epistemic setting (or environment). The physical design refers to the physical elements of the learning environment, such as artefacts, tools and resources, including both material and digital elements. The social design refers to elements such as the design of roles and the division of labour such as groups or teams. Lastly, the epistemic design refers to the tasks that learners undertake. The combination of these three elements would lead to emergent activity and possible outcomes, which, in the case of education, is that of learning.

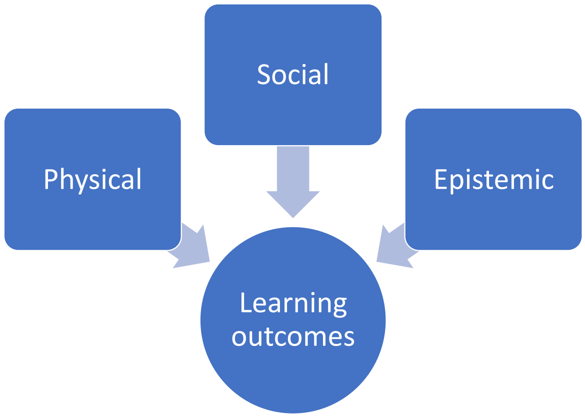

Figure 1. Activity-Centred Analysis and Design framework (adapted from Carvalho & Goodyear, 2018 [2]).

A study found that the design of learning environments can influence how learners perceive pedagogical practices [10], meaning that learner behaviour may possibly be transformed by altering the learning environment. Physical learning environments in classrooms have traditionally been designed in the manner of row-by-row sitting, where students face the front of the classroom, where the teacher is [39]. However, this form of classroom design is contrary and possibly detrimental to the participatory nature of learner-centric pedagogies. As such, more contemporary learning spaces have been designed with rounded and movable tables, which are targeted at facilitating collaboration and discussions [40]. In addition, some spaces include the installation of multiple screens around the classroom for ease of viewing material, as well as the inclusion of in-class devices to facilitate online collaborative activities [41]. This inclusion of technology into learning environments highlights the increasing importance of the role technology plays in learning and learning environments.

Therefore, by taking into consideration the neuroscience-informed principles of learning, it may be possible for educators to utilise a social constructivist-focused learning environment to plan for lessons or activities that facilitate learning and interest development in students to enhance their overall learning experience. As highlighted earlier, the aim of this study is therefore to investigate how neuroscience-informed design principles can be used to guide the design of learning environments that facilitate learning and interest development.

3. Methodology

3.1. Context and Participants

This paper is based on a larger set of data collected from the first author's PhD study examining the impact of interest-driven learning on students' learning and interest development.

The research site for this study is a specialised high school in Singapore, which caters to students who are less academically inclined by offering more technical subjects such as robotics and retail and hospitality education. The school leaders value the process of learning more than the result, which can be seen in how the teachers conduct their lessons to cultivate the joy of learning and interest in students. Examples of this include the use of relatable examples during teaching such as the latest video games or television shows to not only engage and interest the students but also make learning relevant for them. This study involved a class of 22 Secondary 1 (Year 7) students, but with one being absent throughout the semester. There were 7 girls and 14 boys among those present. This group of students came together once a week for two hours each session, where they engaged in coding activities. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by University of Queensland Human Ethics Committee B (Approval number: 2018002401).

The lessons were conducted in the Internet of Things (IoT) classroom (Figure 2), which was arranged and equipped differently from a typical classroom, which has rows of desks facing the teacher and a board at the front of the classroom. The tables were arranged to facilitate discussions and included charging ports for the students' laptops. The room was equipped with a Google Home device, which allowed the teacher to control the projector, screen, window blinds and lights with his voice. This was also to practically show the students the affordances of IoT and how it can practically impact their learning.

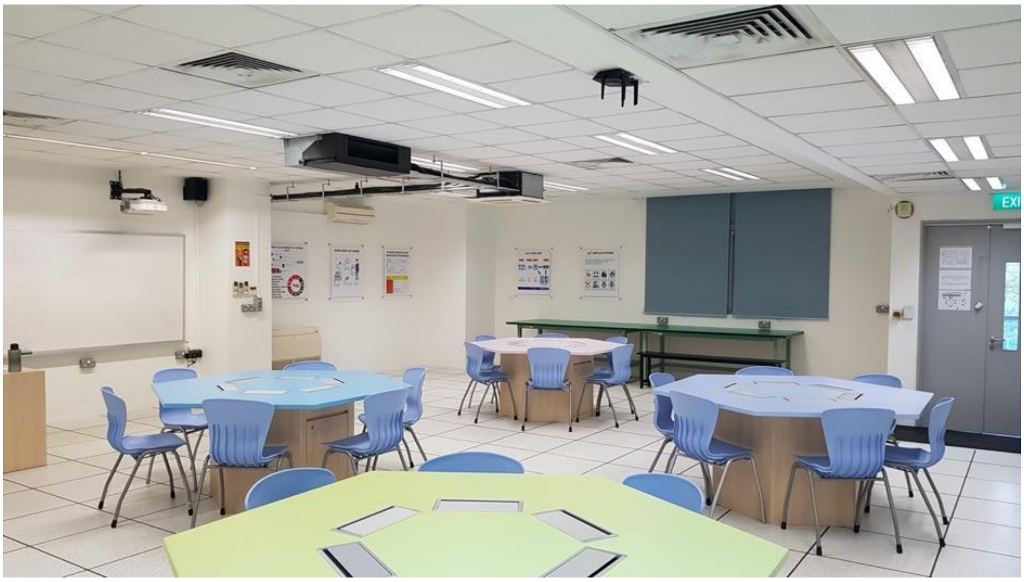

Figure 2. Layout of the IoT classroom.

3.2. Development of the Curriculum

The study employed a design-based approach to incorporate both research and practice in order to increase the impact and transfer of research into teaching practice by capitalising on the strengths of both the researcher and practitioner [42]. At the same time, this approach enables the testing of research and theory in classroom settings [43], which will help further the extant theoretical work already carried out. The first author worked closely with the teacher to develop 10-week lessons based on the interdisciplinary area of Science, Technology, Engineering and Mathematics (STEM) subjects. In particular, these series of lessons were focused on using micro:bit, a handheld programmable computer, to introduce coding to the students in a fun and non-stressful manner. The co-design efforts between the researcher and teacher allowed the teacher to provide inputs to ensure that the content was suitable and manageable by the students. The lessons included segments of formal instruction to facilitate the teaching of new concepts, hands-on segments and two assessments. The lessons were planned in a formulative manner, where the students started with simpler content such as basic circuitry and coding, further progressing into how programming works coupled with hands-on learning activities and eventually culminating in the final session where students were tasked with creating a final project using the micro:bit and the knowledge they accumulated over the whole term.

The activities were designed in accordance with Goswami's [26] neuroscience principles of learning as well, as highlighted in Table 1.

Table 1. Mapping Goswami's [26] principles into activity design.

Goswami's Principles	Activity Design
Learning is incremental and experience-based	Formative activities building upon one another Reasonably paced Limited new content taught per lesson All lessons included a hands-on component
Learning is multi-sensory	Multimodal forms of instruction used
Brain mechanisms of learning extract structure from input	Time provided for students to tinker and reflect Scaffolding provided
Learning is social	Classroom arranged to encourage discussion Group-based activities
Cortical learning can be modulated by phylogenetically (evolutionarily) older systems	Safe and open learning environment Positive space for 'failing'
Learning shows life-long plasticity and development (Neuroplasticity)	Content accessible to all learners

In accordance with the first principle that learning is *incremental and experience-based*, the lessons and activities were formative, building upon content learnt from previous sessions. The content was delivered in manageable amounts and at a reasonable pace to ensure students were able to keep up and understand the content. All the lessons also included hands-on learning segments to provide students with a more immersive experience, which would make learning more tangible. The second principle of learning is *multi-sensory*, which is realised through the multimodal delivery of content. Other than the teacher's verbal delivery of content, visual aids like pictures, diagrams and videos were also used to present learning concepts to students. Hands-on activities such as crafting and programming the micro:bit, and the opportunity to move around the class to interact with one another for various activities, would provide students with multi-sensory learning opportunities. The lessons provided students with ample time to not only learn the content but also to reflect and tinker. This allows the brain to *extract commonalities and structure from input*. For instance, as students were tasked with programming the micro:bit as a temperature alarm, they were given time to reflect on what they had learnt previously. These connections would strengthen their conceptual understanding of what they may have been previously exposed to in class, such as the concepts of heat. Students were also given opportunities to conduct research as well as receive instruction and guidance from teachers. This combination of discovery and the direct transmission of knowledge provided them with a pool of content knowledge and skills to extract principles of coding and critical thinking. The fourth principle states that *learning is social*, and this is enacted in the various activities where the students were tasked to work together and facilitated by the arrangement of the tables. In line with the fifth principle that *cortical learning is modulated by phylogenetically older systems*, or, more specifically, that cognitive and emotional processes are linked and incorporated at numerous levels in the brain, the learning environment and culture within the class were ones of openness and trust. The teacher had to ensure that the culture in the class was one that encouraged students to try without the fear of failing. This was accomplished through providing positive feedback and through friendly competitions to engage the students both cognitively and emotionally. The sixth principle, that learning shows life-long plasticity, means that the lessons were designed in a manner that makes it accessible for learners at all levels to participate, regardless of whether they had a coding background or not. Table 2 provides an overview of the design activities.

Table 2. Overview of activities.

Session Number	Topic	Description
1	Safety and wellbeing in the lab	Students introduced to lab equipment and safe practices in a lab
2	Introduction to electricity and circuits	Introduction to electricity and the different types of circuits. Included a hands-on component of creating circuits
3	Introduction to micro:bit and coding	Introduction to the Internet of Things, the micro:bit and coding using Makecode
4	Theory test and revision	Test student understanding of the first three sessions
5	Writing code: Using buttons and the accelerometer on the micro:bit; loading a code onto the micro:bit	Introduction to the micro:bit hardware, basic coding and the transferring of code from Makecode to the micro:bit
6	Basics of connecting additional hardware to the micro:bit (e.g., LEDs)	Integrating additional components (LED) to the micro:bit
7	Practical test (coding, loading of code)	Practical test for gauging student understanding of the coding process
8	Self-directed exploration of the micro:bit	Students given the opportunity to tinker and self-explore the micro:bit
9	Introduction to radio frequency and temperature sensors on the micro:bit	Introduction to the use of radio-frequency to enable micro:bits to communicate with each other; introduction to the temperature sensor module
10	Creating a temperature alarm	Students tasked to work in groups to create a temperature alarm using what they had learnt in the previous sessions

3.3. Measures

This study employed both quantitative and qualitative measures for data collection. The STEM Interest Survey, adapted from Renninger and Schofield's STEM Tipping Point Survey [44], was used to determine students' interest level in STEM subjects and to track these changes over the course of the semester. The original survey STEM Tipping Point survey was used to measure college students' perceptions of their STEM coursework. The original 15-item survey was administered with 4,125 students, and the items formed one factor (Alpha = 0.912), suggesting a good fit. The STEM Interest Survey uses a six-point Likert scale ranging from one (none at all) to six (a large amount) and includes questions such as 'how easy is it for you to lose track of time when doing math, science or engineering problems'. The survey was administered at the start, middle and end of the semester. However, it has been argued that self-report questionnaires have limitations such as how individuals perceive themselves [45], individual beliefs, memory and peer pressure [46]. It was also suggested that interest research should move beyond self-report measures to more observational methods [20]. This study therefore employed a narrative inquiry approach to triangulate with the results collected from the surveys.

A narrative inquiry approach is adopted, specifically using lesson observations and the recording of field notes. A narrative inquiry space consists of three dimensions: personal, temporal and place dimensions [47]. This means that a study site/subject would include the recording of social interactions (personal) at particular times (temporal), situated within a particular location (place). Lesson observations and field notes were used to record the behaviour and interactions of the students with each other and the learning content. The lesson observations will then be analysed using the ACAD framework's physical, social and epistemic dimensions. Video recording was initially planned, but the school leaders were not comfortable with having their students and teachers recorded, so only field notes were recorded.

4. Analysis and findings

4.1. STEM Interest Survey Results

The STEM Interest Survey results were analysed using non-parametric quantitative analyses, as the current sample size is too small to run parametric analyses, and the data are ordinal in nature as well [48]. The Friedman's non-parametric test and Wilcoxon signed-rank non-parametric test were performed on the STEM Interest Survey responses collected from the students. Friedman's non-parametric analysis was run to test for differences at the three timepoints (pre, mid and post). Table 3 shows the descriptive results from this test, and Table 4 shows the mean ranks from the Friedman test.

Table 3. Descriptive Statistics of the Friedman Test.

	N	Mean of Survey Results	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
Mean Pre	18	3.61	0.78	2.27	4.93	3.02	3.63	4.18
Mean Mid	18	3.51	0.87	1.80	4.80	2.90	3.33	4.23
Mean Post	18	3.77	0.86	1.93	5.13	3.07	3.87	4.47

Table 4. The Mean Ranks at pre, mid and post on the Friedman Test.

	Mean Rank
Mean Pre	2.11
Mean Mid	1.75
Mean Post	2.14

There was no significant main effect of a change in STEM interest as a result of the curriculum intervention ($\chi^2(2) = 1.768$, $p = 0.413$). It should be noted that the number of respondents was 18, as 3 students did not complete the surveys at all three timepoints.

A Wilcoxon signed-rank test was conducted, as it allowed for a comparison between two sets of scores from the same group of respondents, in order to investigate the changes from one timepoint to another. The results are presented in Tables 5 and 6 below.

Table 5. Descriptive Statistics of the Wilcoxon Signed-rank Test.

Descriptive Statistics								
	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
Mean Pre	21	3.55	0.85	2.20	4.93	2.77	3.60	4.30
Mean Post	20	3.67	0.89	1.93	5.13	3.07	3.73	4.35

Table 6. Wilcoxon Signed-rank Test Ranks.

		N	Mean Rank	Sum of Ranks
Mean Post–Mean Pre	Negative Ranks	9 [a]	8.61	77.50
	Positive Ranks	9 [b]	10.39	93.50
	Ties	2 [c]		
	Total	20		

[a] Mean Post < Mean Pre. [b] Mean Post > Mean Pre. [c] Mean Post = Mean Pre.

The Wilcoxon signed-rank test results showed that the 10-week, once-weekly intervention sessions did not generate a statistically significant change in students' interest in STEM-related topics ($Z = -0.349$, $p = 0.727$). The median STEM interest rating, with possible responses ranging from 'one' to 'six', was three both pre- and post-intervention.

Even though the post-tests both show a slight increase in the mean level of interest as compared to the pre-test, both the Friedman test and the Wilcoxon signed-rank test showed an insignificant change in the mean STEM Interest Survey results.

Table 7 shows the results of individual students' pre, mid and post scores on the STEM Interest Survey (out of a possible 90). Student S014 is the student who was absent throughout the semester, resulting in his scores being 0. A total of 10 of the students (47.6%) showed an increase in their interest at the end of the semester, as compared to that at the beginning. Students with higher interest scores in the pre-test appeared to experience a decrease in their interest by the end of the semester (e.g., S007, S017, S019).

Table 7. Individual student changes over time.

Student ID	Gender	Pre-Test Score	Mid-Test Score	Post-Test Score	Percentage Change
S001	F	33	0	32	−3%
S002	F	40	27	29	−38%
S003	F	68	63	77	12%
S004	F	48	44	46	−4%
S005	F	61	50	50	−22%
S006	F	54	49	58	7%
S007	F	69	55	54	−28%
S008	M	39	43	0	9%
S009	M	70	65	70	0%
S010	M	58	41	59	2%
S011	M	46	42	58	21%
S012	M	61	69	71	14%
S013	M	50	61	59	15%
S014	M	0	0	0	0%
S015	M	51	49	46	−11%
S016	M	34	42	45	24%
S017	M	74	70	66	−12%
S018	M	55	50	47	−17%
S019	M	69	0	51	−35%
S020	M	43	46	43	0%
S021	M	58	72	77	25%
S022	M	37	31	63	41%

4.2. Lesson Observations

The students in the class had varying levels of understanding regarding STEM and coding, as observed during the first lesson, when the teacher asked them to raise their hands as an indication of whether they had prior knowledge on STEM and coding. Overall, the class was relatively well-behaved and would engage with the tasks set for them. The female students would usually sit together around the same table and were typically quieter and less responsive than the male students. However, all the students were generally engaged during hands-on activities, not only focused on the task but also actively interacting with one another and discussing how best to accomplish the tasks. One example involved students S011, S012 and S013, who appeared to be good friends, as they chose to sit together at the same table during the first lesson. Throughout the semester, they were observed to be highly interactive with one another, chatting and discussing how to solve the various tasks given to the class, and even having friendly competitions with each other regarding, for example, who could program the micro:bit the fastest. The physical arrangement of the classroom and tables facilitated the discussion among students, and the presence of the charging ports for every student ensured that they were able to use their laptops for coding and research without fear of running out of power.

Over the course of the semester, the students were observed to develop rapport and teamwork as a result of the regular interactions with one another. For instance, S009, S016 and S017 did not appear to know one another prior to this semester, but by the final session, they were able to work well with one another, as they were tasked to work on building a temperature sensor together. Each of them volunteered to work on different components, with S009 and S016 working on the coding of the micro:bit, while S017 worked on the preparation of the presentation slides. When S017 was struggling to complete the presentation slides, S009 offered to help him as well. It was also observed that when S016 was nervous prior to the presentation, S009 and S017 encouraged him and supported him during the presentation. Eventually, the group was able to complete their task and successfully present their end product to the class.

A common theme that was observed across the sessions was that ample time was provided during the sessions to allow students to work on the various tasks. This included time to tinker and explore the functions of the micro:bit, time to conduct their own self-directed research on possible ways to code the temperature sensors and even time to collaborate and discuss with one another. Together with the lessons being delivered in incremental experiences, the ample time for exploration made the learning of new content accessible to the students, as it afforded them time to reflect on what they had learnt, too. In addition, the teacher was present to provide additional guidance and advice for students who might still be struggling.

Though the teacher only saw the class once a week for two hours, he seemed to have established quite a good rapport with the students and was able to connect and engage with them effectively. Possibly as a result of this, he created a class culture whereby the students were willing to participate in the tasks and even fail or get the wrong answer, as the class had an environment of celebrating the spirit of learning and not just obtaining the correct answers. A common observation was that whenever a student volunteered to answer or go up to the board to solve a question, the teacher would affirm the student and also asked the class to clap and affirm them too, regardless of whether the answer given was correct or incorrect.

The teacher was the main person delivering and facilitating the lessons. He conducted the lessons in a manner that was relatively accessible to the students through the use of appropriate scaffolding and also by making it relevant for them, such as by providing day-to-day examples like computer games or movies. During the segments when students were given time to program their micro:bit or complete a complex task, such as creating an alarm system, the teacher was observed to be going around the class to provide inputs and help groups who had difficulty in progressing. The varied and scaffolded tasks helped students engage with the newly learnt content in an accessible manner, without deterring students from participating in class. However, it was also observed that students were engaged during tasks, which presented a certain degree of challenge for them as compared to tasks that were too easy. One example was student S016, who was generally observed to be highly engaged and enthusiastic throughout most of the lessons but appeared bored upon the completion of a task (coding the micro:bit to display arrows in the direction it was tilted toward). He then appeared distracted throughout the remainder of the lesson.

5. Discussion

Based on the STEM Interest Survey, approximately 42% of the class showed a decrease in their interest levels. Possible reasons for the decrease could be that the tasks may not be sufficiently challenging enough for those who have higher ability, or the students may have had a different perception of what STEM involves, and this semester made them realise that they may not be interested in it. An example would be student S017, who had the highest score at the start of the semester but saw a decrease by the end of the semester.

Despite the mixed results of interest from the STEM Interest Survey, the lesson observations showed that all the students were highly engaged and interested in the lessons, supporting Renninger and Bachrach's [20] comment of employing observational methods for interest research. Interest was observed to be triggered in students during various instances as well. For example, some students' interest was triggered when learning new content such as when the teacher was teaching a new concept or when the students were researching ways to code an alarm system. Interest was also observed to be triggered when students were given some form of choice, such as during segments where they were allowed to explore and tinker around with the micro:bit. Social interaction was also observed to be a trigger of interest, such as when students were engaged in group tasks or helping their classmates. Having a group with similar interests to bounce ideas and work toward a common goal therefore appears to have a positive impact on interest development.

Based on the findings of the study, a set of design principles for facilitating student interest and learning were developed: the Task, Environment and Knowledge Creation (TEK) principles. The TEK principles include three main components:

1. Task: Incrementally challenging but scaffolded tasks
2. Environment: Create a familiar and positive learning environment
3. Knowledge Creation: Provide ample opportunities for interaction and reflection

The first design principle on *Task* involves creating tasks and/or activities that are incrementally challenging, while ensuring that sufficient scaffolding and support are provided. For instance, the lessons were structured in a scaffolded manner, with new content being first explained by the teacher, followed by dialogic teaching such as discussions and questioning. Following that, the students were typically given opportunities to engage in hands-on tasks which build upon what had been taught. Together with the use of video and other media, the hands-on activities also provide multi-sensory learning experiences for the students, which is one of Goswami's principles of learning [26]. Neuroplasticity is the process whereby the brain develops and adapts based on responses to the environment [32] and occurs throughout the lifespan. This means that it is important to account for learners' strengths and limitations when developing teaching and learning tasks for students [49]. It is therefore important for the teacher to constantly be aware of and adjust the complexity of the tasks set, depending on the students' ability. This could include increasing the complexity of tasks to ensure the students are being sufficiently challenged or providing additional support if the students find the tasks too difficult. Furthermore, when learners are sufficiently challenged, it will lead to increased engagement [50] and optimal learning [51]. This is supported by observations from this study, where the students were observed to be engaged when given a challenging task, as compared to when they were given a simple task, at which point they were observed to lose interest and were seen searching for videos or games online instead. Another aspect to consider is that tasks need to be relevant to the learners. By engaging with tasks that are personally meaningful to them, learners are able to make meaning out of these experiences, leading them to be more motivated to continue engaging with the activity [52]. This can be accomplished through the use of relevant examples to the learners or contextualising the tasks to their social environment or culture. An example from the study was the use of examples by the teacher related to video games, social media trends and local food and games.

The second design principle of *Environment* relates to the creation of a familiar and positive learning environment for the learners. Arndt [53] highlighted the importance of designing learning spaces to nurture positive affective and cognitive development. Teachers are placed in a position where they can influence both the physical design and the culture of the classroom to create a safe and positive learning environment for the students [54]. This can be achieved by creating a comfortable and familiar environment, such as having a fixed room, which can be personalised in its layout and decorations. For instance, the school in this study had a fixed room (the IoT room), where the weekly lessons were carried out. The room had posters on wearable technology, safety in the lab and the possibilities of what the Internet of Things can provide. It also incorporated the use of

Google Home technology, where the lights, blinds and projectors could be turned on and off by using voice commands. This provided an increased level of immersion of the use of such technology in daily lives. The tables were also arranged in a way that facilitated interaction and discussion among the students and the teacher. This supports Baepler and Walker's [36] findings that the design of a learning environment has the potential to facilitate the development of positive relationships between learners. A sense of familiarity also enabled the students to be more engaged with the lessons. Of equal, or perhaps even greater, importance compared to the physical environment is the role a supportive teacher plays in creating a culture of openness and trust [55]. As the teacher interacts positively with the students and encourages them in class, the students themselves develop positive views of themselves and are more confident in speaking up in class or attempting novel tasks [56]. This was evidenced in the current study, where the teacher encouraged students to attempt to answer questions on the whiteboard or verbally, and even if they did not answer the questions completely correctly, he provided positive encouragement to the student and also asked the class to encourage the student by clapping their hands. As a result of this, it was observed that the students in the class felt safe to attempt answering questions without fear of judgement or ridicule from their classmates. By being in an environment where there is support, trust and positive learning experiences, students will be able to experience positive physiological arousal such as feelings of enjoyment, interest and joy.

The third design principle is *Knowledge Creation*, which refers to providing ample opportunities for interaction and reflection. Goswami [26] highlighted that learning is social, echoing the theory of social constructivism, which emphasises the role social expectations play in cognitive development and how learning reaffirms these social expectations to enable the assimilation and development of knowledge [34]. Through the establishment of support from teachers and peers, learners will be uninhibited by fears and anxiety to become self-reliant individuals who can explore and immerse themselves in constructive tasks and interactions with others [57], affording them the opportunities to explore and nurture their interests. Students in the study exhibited positive affect and engagement with the learning content when interacting with their peers. Research by Immordino-Yang, Christodoulous and Singh [31] found that when students were engaged in an activity that is emotionally meaningful and personally relatable, the default mode network in the brain responsible for attention and conceptual understanding becomes activated. Even though more empirical research may be required, it is reasonable to believe that, as students experience positive emotions in class, even if they are not from the task itself, they may be more attentive and be able to better understand the task. This design principle therefore suggests that learning tasks include a component of social interaction among students. One other suggestion is for teachers to ensure that lessons are not overly packed with content but rather allow time for learners to tinker and reflect, which allows for meaning making to take place [58]. This form of reflection, especially on any mistakes they have made, can be supported by teachers to help students gain insight into their mistakes. If carried out well, students will not only be able to learn from their mistakes but will grow in self-confidence and possibly develop an interest in the subject matter. If every lesson is fully packed, the teacher may be so busy trying to complete the contents of the lesson that there may be little regard for whether the students have internalised and understood what was taught. In the current study, the lessons typically included activities that provided opportunities for students to work together and interact with each other, as well as pockets of time where students are allowed to tinker with the micro:bit. This afforded opportunities for students to assimilate what they had just been taught and to reflect on alternative ways they could have solved the tasks. The students were found to be engaged during these tinkering segments of the lesson, as evidenced by observations.

These TEK design principles can therefore be seen as a lens through which the learning environment can be viewed to design learning activities and a curriculum facilitating learning and interest development in learners (Figure 3). By implementing these design principles, the learning environment can be better planned to facilitate learning and interest development outcomes.

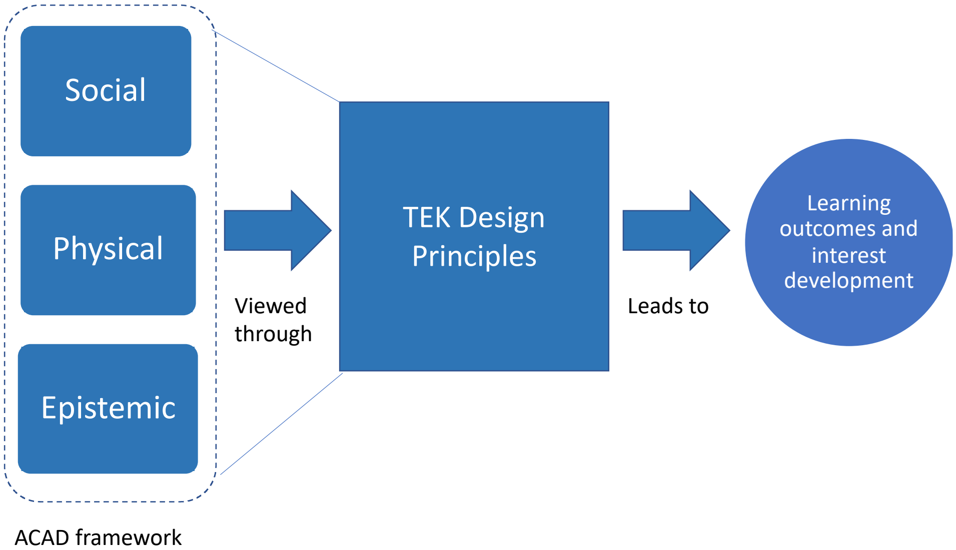

Figure 3. Integrating TEK Design Principles into the ACAD framework.

6. Implications

The development of the TEK design principles has implications for both research and practice. The TEK design principles contribute to the extant learning environments research by integrating neuroscience principles into the task and, subsequently, design principles. At the present moment, there is limited research into neuroscience and learning environments research, especially in a high school setting. The TEK design principles also provide a theoretical framework for researchers to use as a set of objective components to evaluate the effectiveness of learning environment designs.

From a policy and practice perspective, the TEK design principles can be used by teachers as a blueprint in formal environments such as classrooms or informal learning environments such as an extracurricular activity space to help them in the setting-up or design of their curriculum or classroom layout. Policymakers and school leaders will also be able to make decisions on investing in the appropriate space design to facilitate learning and interest development within their students. With the COVID-19 pandemic taking learning in many countries from the physical space to the digital realm, these design principles may also be applied in the creation of digital learning environments to aid teachers in developing 'rules', creating a safe and interactive learning environment.

7. Limitations

One limitation of the present study is that it has a small population size. A study with a larger population will be able to generate more generalisable data. However, this study is able to provide the development of a possible set of design principles that can be further tested in larger populations. Another limitation was the limited access to students and teachers. At the time of study, the school leaders did not allow for video recording or the interview of students, as they were concerned about their well-being and the confidentiality of their identities. The results were therefore based on survey results and researcher observations. The use of interviews in future studies will be able to provide more in-depth and richer perspectives on how the three components of the TEK design principles have an impact on learners' learning and interest.

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References

1. So, H.-J.; Brush, T.A. Student perceptions of collaborative learning, social presence and satisfaction in a blended learning environment: Relationships and critical factors. *Comput. Educ.* **2008**, *51*, 318–336. [CrossRef]
2. Carvalho, L.; Goodyear, P. Design, learning networks and service innovation. *Des. Stud.* **2018**, *55*, 27–53. [CrossRef]
3. Fredrickson, B.L.; Branigan, C. Positive emotions. In *Emotions*; Mayne, T.J., Bonanno, G.A., Eds.; The Guilford Press: New York, NY, USA, 2000; pp. 123–151.
4. Fryer, L.K. Getting interested: Developing a sustainable source of motivation to learn a new language at school. *System* **2019**, *86*, 102120. [CrossRef]
5. Renninger, K.A.; Hidi, S.E. *The Power of Interest for Motivation and Engagement*; Routledge: New York, NY, USA, 2016.
6. Tan, A.L.; Hung, D.; Jamaludin, A. Exploring the Dimensions of Interest Sustainability (5Cs Framework): Case Study of Nathan. In *Innovations in Educational Change. Education Innovation Series*; Hung, D., Lee, S.S., Toh, Y., Jamaludin, A., Wu, L., Eds.; Springer: Singapore, 2019; pp. 253–276.
7. Temple, P. Learning spaces in higher education: An under-researched topic. *Lond. Rev. Educ.* **2008**, *6*, 229–241. [CrossRef]
8. Thomas, C.L.; Pavlechko, G.M.; Cassady, J.C. An examination of the mediating role of learning space design on the relation between instructor effectiveness and student engagement. *Learn. Environ. Res.* **2019**, *22*, 117–131. [CrossRef]
9. Valtonen, T.; Leppanen, U.; Hyypia, M.; Kokko, A.; Manninen, J.; Vartiainen, H.; Sointu, E.; Hirsto, L. Learning environments preferred by university students: A shift toward informal and flexible learning environments. *Learn. Environ. Res.* **2020**, *24*, 371–388. [CrossRef]
10. Verdonck, M.; Greenaway, R.; Kennedy-Behr, A.; Askew, E. Student experiences of learning in a technology-enabled learning space. *Innov. Educ. Teach. Int.* **2019**, *56*, 270–281. [CrossRef]
11. Krapp, A. Interest and human development: An educational-psychological perspective. *Br. J. Educ. Psychol.* **2003**, 57–84.
12. Hidi, S.; Renninger, K.A. The four-phase model of interest development. *Educ. Psychol.* **2006**, *41*, 111–127. [CrossRef]
13. Dohn, N.B. Situational interest of high school students who visit an aquarium. *Sci. Educ.* **2011**, *95*, 337–357. [CrossRef]
14. Hidi, S.; Renninger, K. Interest development and its relation to curiosity: Needed neuroscientific research. *Educ. Psychol. Rev.* **2019**, *31*, 833–852. [CrossRef]
15. Maltese, A.V.; Harsh, J.A. Student's pathways of entry into STEM. In *Interest in Mathematics and Science Learning*; Renninger, K.A., Nieswandt, M., Hidi, S., Eds.; American Educational Research Association: Washington, DC, USA, 2015; pp. 203–223.
16. Crouch, H.C.; Wisittanawat, P.; Cai, M.; Renninger, K.A. Life science students' attitudes, interest, and performance in introductory physics for life sciences: An exploratory study. *Phys. Rev. Phys. Educ. Res.* **2018**, *14*, 010111. [CrossRef]
17. Trautwein, U.; Ludtke, O.; Nagy, N.; Lenski, A.; Niggli, A.; Schnyder, I. Using individual interest and conscientiousness to predict academic effort: Additive, synergistic, or compensatory effects? *J. Personal. Soc. Psychol.* **2015**, *109*, 142–162. [CrossRef] [PubMed]
18. Patall, E.A.; Vasquez, A.C.; Steingut, R.R.; Trimble, S.S.; Pituch, K.A. Daily interest, engagement, and autonomy support in the high school science classroom. *Contemp. Educ. Psychol.* **2016**, *46*, 180–194. [CrossRef]
19. Patall, E.A.; Hooper, S.Y. The promise and peril of choosing for motivation and learning. In *The Cambridge Handbook of Motivation and Learning*; Renninger, K.A., Hidi, S.E., Eds.; Cambridge University Press: Cambridge, UK, 2019; pp. 238–264.
20. Renninger, K.A.; Bachrach, J.E. Studying triggers for interest and engagement using observational methods. *Educ. Psychol.* **2015**, *50*, 58–69. [CrossRef]
21. Burkhardt, H.; Schoenfeld, A.H. Improving educational research: Towards a more useful, more influential and better-funded enterprise. *Educ. Res.* **2003**, *32*, 3–14. [CrossRef]
22. McWilliam, E.; Lee, A. The problem of "the problem with educational research". *Aust. Educ. Res.* **2006**, *33*, 43–60. [CrossRef]
23. Morris, J.; Sah, P. Neuroscience and education: Mind the gap. *Aust. J. Educ.* **2016**, *60*, 146–156. [CrossRef]
24. Dekker, S.; Lee, N.C.; Howard-Jones, P.; Jolles, J. Neuromyths in education: Prevalence and predictors of misconceptions among teachers. *Front. Psychol.* **2012**, *3*, 429. [CrossRef]
25. De Jong, T. Cognitive load theory, educational research, and instructional design: Some food for thought. *Instr. Sci.* **2010**, *38*, 105–134. [CrossRef]

26. Goswami, U. Principles of learning, implications for teaching: A cognitive neuroscience perspective. *J. Philos. Educ.* **2008**, *42*, 381–399. [CrossRef]
27. Piaget, J. *The Origins of Intelligence in Children*; Basic Books: New York, NY, USA, 1953.
28. James, K.H. Sensori-motor experience leads to changes in visual processing in the developing brain. *Dev. Sci.* **2010**, *13*, 279–288. [CrossRef] [PubMed]
29. Tan, A.L. Bridging the Gap between Formal and Informal Learning: An Application of Neuroscience to Improve Student Learning Outcomes through Interest-Driven Learning. Ph.D. Thesis, University of Queensland, St Lucia, QLD, Australia, 2021. Available online: https://espace.library.uq.edu.au/view/UQ:2dadff9 (accessed on 1 December 2022).
30. Tai, Y.F.; Scherfler, C.; Brooks, D.J.; Sawamoto, N.; Castiello, U. The human premotor cortex is 'mirror' only for biological actions. *Curr. Biol.* **2004**, *14*, 117–120. [CrossRef] [PubMed]
31. Immordino-Yang, M.H.; Christodoulou, J.A.; Singh, V. Rest is not idleness: Implications of the brain's default mode for human development and education. *Perspect. Psychol. Sci.* **2012**, *7*, 352–364. [CrossRef]
32. Elmore, R.F. The future of learning and the future of assessment. *ECNU Rev. Educ.* **2019**, *2*, 328–341. [CrossRef]
33. Vygotsky, L.S. *Mind in Society: The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, MA, USA, 1978.
34. Booyse, C.; Chetty, R. The significance of constructivist classroom practice in national curricular design. *Afr. Educ. Rev.* **2016**, *13*, 135–149. [CrossRef]
35. Miyake, N.; Kirschner, P.A. The social and interactive dimensions of collaborative learning. In *The Cambridge Handbook of the Learning Sciences*; Sawyer, R.K., Ed.; Cambridge University Press: Cambridge, UK, 2014; pp. 418–438.
36. Baepler, P.; Walker, J.D. Active Learning Classrooms and Educational Alliances: Changing Relationships to Improve Learning. *New Dir. Teach. Learn.* **2014**, *137*, 27–40. [CrossRef]
37. Baepler, P.; Walker, J.D.; Driessen, M. It's Not about Seat Time: Blending, Flipping, and Efficiency in Active Learning Classrooms. *Comput. Educ.* **2014**, *78*, 227–236. [CrossRef]
38. Campbell, L. Teaching in an Inspiring Learning Space: An investigation of the extent to which one school's innovative learning environment has impacted on teachers' pedagogy and practice. *Res. Pap. Educ.* **2020**, *35*, 185–204. [CrossRef]
39. Beichner, R.J.; Saul, J.M.; Allain, R.J.; Deardorff, D.L.; Abbott, D.S. Introduction to SCALEUP: Student-Centered Activities for large Enrollment University Physics. Charlotte. 2000. Available online: https://eric.ed.gov/?id=ED459062 (accessed on 11 November 2022).
40. Casanova, D.; Huet, I.; Garcia, F.; Pessoa, T. Role of Technology in the Design of Learning Environments. *Learn. Environ. Res.* **2020**, *23*, 413–427. [CrossRef]
41. Mei, B.; May, L. Reflective Renovation: Insights from a Collaborative and Active Learning Space Project Evaluation. *Australas. J. Educ. Technol.* **2018**, *34*, 17–26. [CrossRef]
42. Anderson, T.; Shattuck, J. Design-based research: A decade of progress in education research? *Educ. Res.* **2012**, *41*, 16–25. [CrossRef]
43. Shavelson, R.J.; Phillips, D.C.; Towne, L.; Feuer, M.J. On the Science of Education Design Studies. *Educ. Res.* **2003**, *32*, 25–28. [CrossRef]
44. Renninger, K.A.; Schofield, L.S. *Assessing STEM Interest as a Developmental Motivational Variable*; Poster Presented at American Educational Research Association: Philadelphia, PA, USA, 2014.
45. Frenzel, A.C.; Pekrun, R.; Dicke, A.L.; Goetz, T. Beyond quantitative decline: Conceptual shifts in adolescents' development of interest in mathematics. *Dev. Psychol.* **2012**, *48*, 1069–1082. [CrossRef]
46. Pekrun, R.; Buhner, M. Self-report measures of academic emotions. In *International Handbook of Emotions in Education*; Pekrun, R., Linnenbrink-Garcia, L., Eds.; Routledge: London, UK, 2014; pp. 561–566.
47. Clandinin, D.J.; Connelly, F.M. *Narrative Inquiry: Experience and Story in Qualitative Research*; Jossey-Bass Publishers: San Francisco, CA, USA, 2000.
48. Fagerland, M.W. t-tests, non-parametric tests, and large studies—A paradox of statistical practice? *BMC Med. Res. Methodol.* **2012**, *12*, 78. [CrossRef] [PubMed]
49. Koch, K.R.; Timmerman, L.; Peiffer, A.M.; Laurienti, P.J. Convergence of two independent roads to collaboration between education and neuroscience. *Psychol. Sch.* **2013**, *50*, 577–588. [CrossRef]
50. Reeve, J.; Halusic, M. How K-12 teachers can put self-determination theory principles into practice. *Theory Res. Educ.* **2009**, *7*, 145–154. [CrossRef]
51. Hattie, J.; Zierer, K. *10 Mindframes for Visible Learning: Teaching for Success*, 1st ed.; Routledge: London, UK, 2018.
52. Immordino-Yang, M.H.; Knecht, D.R. Building meaning builds teens' brains. *Educ. Leadersh.* **2020**, *77*, 36–43.
53. Arndt, P.A. Design of Learning Spaces: Emotional and Cognitive Effects of Learning Environments in Relation to Child Development. *Mind Brain Educ.* **2012**, *6*, 41–48. [CrossRef]
54. DeVries, R. Vygotsky, Piaget, and education: A reciprocal assimilation of theories and educational practices. *N. Ideas Psychol.* **2000**, *18*, 187–213. [CrossRef]
55. León, J.; Núñez, J.L.; Liew, J. Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learn. Individ. Differ.* **2015**, *4*, 156–163. [CrossRef]

56. Farmer, T.W.; McAuliffe Lines, M.; Hamm, J.V. Revealing the invisible hand: The role of teachers in children's peer experiences. *J. Appl. Dev. Psychol.* **2011**, *32*, 247–256. [CrossRef]
57. Furrer, C.J.; Skinner, E.A. Sense of Relatedness as a Factor in Children's Academic Engagement and Performance. *J. Educ. Psychol.* **2003**, *95*, 148–162. [CrossRef]
58. Bozkurt, G. Social constructivism: Does it succeed in reconciling individual cognition with social teaching and learning practices in mathematics? *J. Educ. Pract.* **2017**, *8*, 210–218.