education sciences

MDPI

Article

A Case Study: Using a Neuro-Physiological Measure to Monitor Students' Interest and Learning during a Micro:Bit Activity

Aik Lim Tan [1,*], Robyn Gillies [2] and Azilawati Jamaludin [1]

[1] National Institute of Education, Nanyang Technological University, Singapore 637616, Singapore; azilawati.j@nie.edu.sg
[2] School of Education, University of Queensland, Brisbane, QLD 4072, Australia; r.gillies@uq.edu.au
* Correspondence: aik.tan1@uqconnect.edu.au

Abstract: Interest plays a critical role in learning and development. It is able to compel students toward short term exploration, motivating them toward the pursuit of future goals, as well as leading to the development of knowledge and cognitive abilities. Interest also enables students to rise above perceived restrictions and limitations to achieve their goals. Interest therefore plays a significant role in learning and development. Currently, most of the extant research on interest has been typically done using self-report surveys or by observations, which may be somewhat subjective in nature. This study therefore aims to further deepen our understanding of the value of interest on learning, and more importantly, suggests a novel method of tracing interest development over time. An alternative measure of interest through the use of neuro-physiological markers is suggested, with examples based on two case studies out of a class of 22 students. The Empatica E4 wristband was used to collect electrodermal activity (EDA) data to capture instances of triggered interest during a 10-week curriculum, which were triangulated with behavioral observations. The study found that EDA is a possible measure for recording and tracing interest development in students, providing a more nuanced and objective measure of interest development.

Keywords: electrodermal activity; interest development; motivation

check for updates

Citation: Tan, A.L.; Gillies, R.; Jamaludin, A. A Case Study: Using a Neuro-Physiological Measure to Monitor Students' Interest and Learning during a Micro:Bit Activity. *Educ. Sci.* **2021**, *11*, 379. https://doi.org/10.3390/educsci11080379

Academic Editor: Eleanor Dommett

Received: 31 May 2021
Accepted: 22 July 2021
Published: 24 July 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

The study of motivation and interest in education has been an area that has gained much traction over the years. One of the key purposes of education is to effectively equip students for life by providing them with the appropriate intellectual tools, self-belief and self-regulatory competencies to ensure they are able to continuously grow and learn throughout their lives [1]. A typical component of education, especially in formal settings, is the presence of assessments, usually in the form of examinations. Despite their utility in assessing students' knowledge and achievement, these assessments, especially if they are high-stakes in nature, have been found to decrease students' motivation for learning [2] even to the extent of affecting children's health due to the pressure, stress, and anxiety they cause [3]. One possible way of mitigating such stress and lack of motivation is through the development of interest.

Interest compels students toward short term exploration, leading to the development of knowledge and cognitive abilities [4], as well as motivation to pursue future goals ([5]. Other than that, the extant literature has found that interest positively impacts students' goals, attention, and learning [6], overcomes perceived disabilities [7], and increases class participation and use of cognitive learning strategies [8]. Currently, interest is typically measured through the use of self-report surveys or ethnographic observations that may be somewhat subjective in nature.

This study therefore aims to examine the value of interest, its impact on learning, and, more importantly, to suggest a novel measure of interest. This paper proposes an alternative measure of interest through the use of neuro-physiological measures, and provides examples in the form of case studies.

2. Literature Review

2.1. Interest Defined

Humans have an innate desire to explore their surroundings and seek out objects they consider to be interesting [5], which by nature would make the process of acquiring knowledge a pleasant experience. Interest has been long recognized to be a critical aspect of motivation for learning [9]. It is a preference and passion for learning [10] facilitated by interaction with the external environment [6].

The study of interest has been an area of attention since the 1970s. Schank [11] first described interest as an emotional state triggered by situational stimuli. Schiefele [12] then identified individual interest as an intrinsic and long-term trajectory toward a specific object of interest. Krapp [5] then contributed to the definition of interest by conceptualizing it as having two levels, with the first level suggesting that interest requires a situation-specific interaction between the individual and an object, and the second level suggesting interest as a predisposition for the individual to sustain interest toward that specific object. For the purposes of this paper, Interest will be defined as the result of interaction between the individual and the environment, and referring to the psychological state as well as the cognitive and affective motivation of an individual to engage with that content of interest over time [13]. This is described as the dual meaning of interest (see Figure 1). What this means is that motivation and interest are interrelated in that engagement with the content may support the development of interest, but at the same time, interest in the content may motivate individuals to maintain engagement with the content as well [13]. For instance, studies have shown that interest is able to not only motivate students to engage in short term exploration [4] but also sustain intrinsic motivation [14]. At the same time, studies have also found that intrinsic motivation is able to trigger and sustain interest in learning [15].

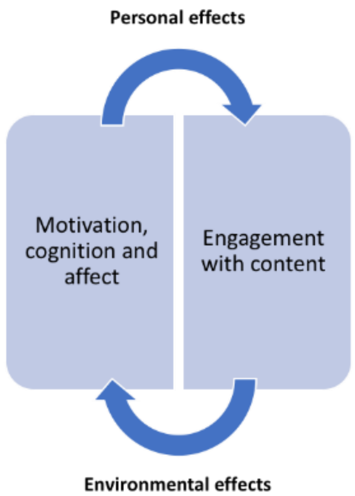

Figure 1. The development of interest. Adapted from Renninger & Hidi, 2016.

There are two types of interest within education research: situational interest and individual interest. Situational interest is an early phase of interest development and refers to an affective response to a specific activity [13] when an individual's attention is directly linked to obtaining a goal [16]. On the other hand, individual interest is a more developed phase of interest and refers to a more persistent inclination to reengage with an object of interest over time [6].

The four-phase model of interest development [6] is one of the most widely used and recognized frameworks of interest. It describes the development of interest across four different phases, with each phase being sequential and progressing from triggered situational interest to maintained situational interest, emerging individual interest, and lastly, well-developed individual interest. The earlier phases are generally characterized by requiring greater support from the external environment to develop as compared to the later phases. Table 1 provides an overview of the characteristics of each phase of interest.

Table 1. The four phases of interest development.

	Phases of Interest Development			
	Less Developed (Earlier) More Developed (Later)			
	Phase 1 (Triggered Situational Interest)	**Phase 2 (Maintained Situational Interest)**	**Phase 3 (Emerging Individual Interest)**	**Phase 4 (Well-Developed Individual Interest)**
Definition	Psychological state resulting from short-term changes in cognitive and affective processing associated with specific content	Psychological state that involves focused attention towards specific content that reoccurs and persists over time	Psychological state and the beginning of relatively enduring predisposition to seek reengagement with specific content over time	Psychological state and a relatively enduring predisposition to reengage specific content over time
Learner characteristics	- Attends to content, if only momentarily - May need support to engage, from others and instruction - May be reflexively aware of experience - May experience positive or negative feelings - May not persevere in face of challenges - May want to be told what to do	- Reengages content that previously triggered attention - Developing content knowledge - Developing sense of content's value - Likely able to be supported by others to find connections to content based on prior skills and knowledge - Likely to have positive feelings - May want to be told what to do	- Likely to independently reengage content - Has stored knowledge and value - Reflective about content - Focused on own questions - Have positive feelings - May not persevere in face of challenges - May not want feedback from others	- Independently reengage content - Has stored knowledge and value - Reflective about content - Likely to recognize others' contributions to discipline - Self-regulates easily to reframe questions and seek answers - Can persevere through challenges to meet goals - Appreciates and may actively seek feedback

Source: Adapted from Renninger & Hidi (2016).

In the context of learning and education, interest has been identified as a precursor to engagement over time [6], characterized by increased focus and attention [17], increased cognitive and affective functioning [13], increased persistent effort and motivation [18], and a desire to find out more about a novel area [19].

2.2. Measuring Interest

Interest relates to an individual's neurological or physiological reactions in response to people, the environment, or specific tasks, manifesting itself behaviorally as increased attention, effort, and changes in affect [13].

Presently, the most commonly used measurement for interest is self-report questionnaires [13]. Some examples of such measures being used in previous studies include the Motivated Strategies for Learning Questionnaire [20], the Student Interest Scale [21], and the Situational Interest Measure [19]. Typically, the administration of questionnaires is considered to be a relatively inexpensive and easy to administer form of data collection in classrooms, making it a commonly used method of data collection [22]. On the other hand, questionnaires are usually self-reported and are heavily dependent on the limitations of the consciousness of individuals and how they perceive themselves [23]. Language and understanding of words and phrases may be interpreted differently across cultures, and be affected by individual beliefs, memory and social pressure as well [22].

In particular for the measurement of interest, Renninger and Bachrach [24] stated that experiences that trigger interest are also usually unanticipated and evanescent, making it challenging to identify and report, even for the individuals themselves. They then went on to suggest that it is imperative for interest research to move beyond the use of self-report measures toward more observational methods to better recognize the factors within learning environments that lead to an increase in interest. An emerging field of research that can complement these self-report measures is that of neurophysiological measures.

2.3. Neurophysiological Measures

The learning process is not an isolated process only occurring within the brain, but also involves temporal activation of various structures within the nervous system [25]. For example, memory and emotion are interdependent in nature, with studies demonstrating that individuals are more likely to remember emotionally charged events, irrespective of whether the emotion experienced was a positive or a negative one [26]. Given that significant outcomes of education involve learning, engagement, and motivation, the study of neuroscience and psychological knowledge has been gaining much interest over the years, with the hope of improving learning outcomes of students [27]. Neurophysiological signals have been recognized to be effective indicators for various cognitive functions such as emotion and attention [28], and has been found to be an appropriate measure for tracing students' cognitive states in a less invasive and more ecologically accurate manner [29]. One such neurophysiological measure, which will be measured in this study, is that of electrodermal activity. Developments in research and technology of such physiological measures have led to many opportunities to measure various physiological responses of an individual in real time [30], thereby creating many new pathways and possibilities for education research.

2.4. Electrodermal Activity

Electrodermal activity (EDA) describes changes in the electrical conductance of the skin, and consists of both slow changes in the basal skin conductance level (SCL) as well as more rapid changes known as skin conductance responses (SCR) [31,32]. SCR are the result of physiological responses toward a transient stimulus [33], making it possible to use these data to identify specific types and duration of an activity that caused an arousal response.

The skin is the primary interface between individuals and the external environment, and is involved in several important biological processes such as the immune system, sensory-motor exploration and thermoregulation [34]. In order to effectively accomplish its many functions, the skin is densely innervated with autonomic innervation of the eccrine sweat glands, which manifests in changes in skin conductance on the surface of the skin [34]. Skin conductivity is induced by moisture produced by the eccrine sweat glands, which occur automatically in individuals, and are most responsive to emotional arousal [35]. Even though there may not be visible sweat on the surface of the skin, sweat is a good conductor of electricity, and the filling of sweat glands due to an autonomic response results in low-resistance parallel pathways, which increases the conductance of an applied current [36], thereby making it possible for EDA readings to be picked up by sensors.

Numerous studies have found EDA to be an effective indicator of attention and cognitive or emotional arousal [34,37–39]. More recent studies have also found positive correlations between SCL and students' academic performance [29], and student achievement during examinations [40]. Arousal, as measured by SCL, is therefore a possible measure of interest as it involves attention, engagement, and positive affect, which are positively correlated with arousal [29,40,41]. A number of classroom-based studies have also suggested EDA conductivity as a valid proxy for engagement and interest [42,43]. A study by Cain and Lee [36] also found that situational interest produces a significant increase in physiological arousal, which was captured as increasing EDA readings.

Traditionally, EDA has been measured at the palmar regions of the hands such as the fingers, where the sweat glands' density is the most concentrated [44]. Electrodes are applied to the skin using gels and a current is applied in order to obtain an EDA reading, which is measured in microSiemens (μS). However, this method of obtaining data is impractical as the gels may wear off over time, affecting the signals being recorded [45]. As a result, much of this sort of research has typically been conducted in a controlled laboratory setting [28].

However, advances in technology has enabled a more ecologically valid and practical method of measuring EDA at the wrist. A number of studies have determined that utilizing the skin's natural hydration and measuring EDA at the wrist is significantly correlated with EDA measured at the fingers [46,47]. These findings suggest that an EDA sensor worn on the wrist in the form of a watch or wristband is a possible alternative measure of EDA.

3. Methodology

The findings of this paper are part of a PhD study examining the impact of interest-driven learning on students' learning and motivation in an informal learning environment where the process is emphasized over the final product [48]. A design-based approach was chosen to develop a curriculum to incorporate research and practitioner input in order to provide an experience that can cultivate interest in students. Design-based research (DBR) facilitates the impact and translation of educational research into improved teaching practices [49], enabling the testing and inception of research and theory in classroom settings [50]. This approach was chosen because it involves and capitalizes on the strengths of both researchers and practitioners [49] to produce the best possible intervention that will benefit students the most. The first author worked closely with the teacher to develop a set of 10 STEM-based lessons using the micro:bit, which is a handheld programmable computer tool to teach coding in a fun and non-intimidating manner.

3.1. Context and Participants

This study took place in a specialized high school offering technical subjects such as retail, robotics, and technology, as well as the usual academic subjects such as math and science. This school and its staff believe in nurturing the joy of learning, instead of simply focusing on students' final grades, through the cultivation of an enjoyable learning environment to cultivate interest in learning. The participants were from a class of 22 Secondary 1 students who came together once a week for two hours for this coding class. This paper will examine two case studies to examine the use of EDA as a measure of interest.

The first student, Daniel (pseudonym), is a 13-year-old male with a positive attitude in class, always offering help to his classmates whenever he completes his tasks earlier. Based on the self-reported STEM Interest Survey, he reported a low interest in STEM subjects, recording the second lowest mean score out of the whole class. However, the lesson observations and EDA recordings collected throughout the term showed otherwise, with him having a high interest in the subject.

The second student, Alex (pseudonym), is a 13 year old male who has a playful disposition who sometimes has a sleepy look of disinterest in class. Based on the STEM Interest Survey, this student reported a high interest in STEM subjects, obtaining the second highest mean score out of the whole class. However, based on the lesson observations and EDA readings, he did not seem interested in the class activities.

In order to prevent any bias of responses, the students were not told that this study was to test their interest. They were informed that the wristbands will be used to measure their sweat levels during the lessons, and that they had to complete some surveys over the course of the term.

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).

3.2. Intervention Curriculum

The curriculum was co-designed by the researcher and teacher, which afforded the opportunity for the creation of STEM-specific lessons in order to explore interest-based learning. This allowed for input from the teacher to cater the content to be suitable and relevant to students' learning. The resulting curriculum was a 10-week series of STEM lessons with one lesson per week. These lessons include segments of formal instruction to facilitate the teaching of new concepts, hands-on segments, and two assessments. The lessons are planned in a formulative manner where the students will start with the basics of STEM such as basic circuitry and coding, culminating in the final session where students will be tasked with creating a final project using the knowledge they have accumulated over the whole term.

3.3. Measures

The STEM-Interest survey. The survey was adapted from Renninger and Schofield's [51] STEM Tipping Point Survey, and was used to determine changes to students' interest over the course of the intervention. The original STEM Tipping Point Survey measured college students' perceptions of their STEM coursework and was used to determine why some continued to pursue a career in STEM but not others. The STEM-Interest survey was adapted to make it more relevant for high school students in a Singapore context, and was used to determine students' interest development and motivation toward STEM.

EDA data. Empatica E4 wristbands were used to obtain EDA data from the four students. These wristbands are able to measure various physiological data such as blood volume, pulse, skin temperature, and EDA [52], and can be worn in a non-invasive manner like a watch. This makes it ideal for this study as it offers ecological validity, enabling the students to participate in class activities without any form of hindrance or inconvenience. A peak detection platform, *EDA Explorer*, was used to identify EDA peaks in the data collected, which are assumed to correspond to increased arousal, and more specifically SCR. An algorithm within this platform that was developed from machine learning through the use of data reviewed by EDA experts was able to identify and remove potential noisy artefacts such as excessive movements, ensuring the peaks recorded were accurate [53]. The detection of peaks would suggest a sudden response to a specific stimulus, which has been observed in traditional laboratory-based studies [54]. This study assumes that a peak would correspond to a stimulus that triggers interest, leading to increased arousal. The absence of a peak would therefore signify a lack of interest in the specific activity or stimulus. In order for the EDA readings to be recorded as peaks, the readings had to be at an amplitude of at least 1.0 μS with a 1.0 s offset. This means that the readings would have to increase for at least 1 s before a peak and decrease for 1 s after a peak in order to be identified as a peak, which will be demarcated by a green vertical line, as seen in Figure 2.

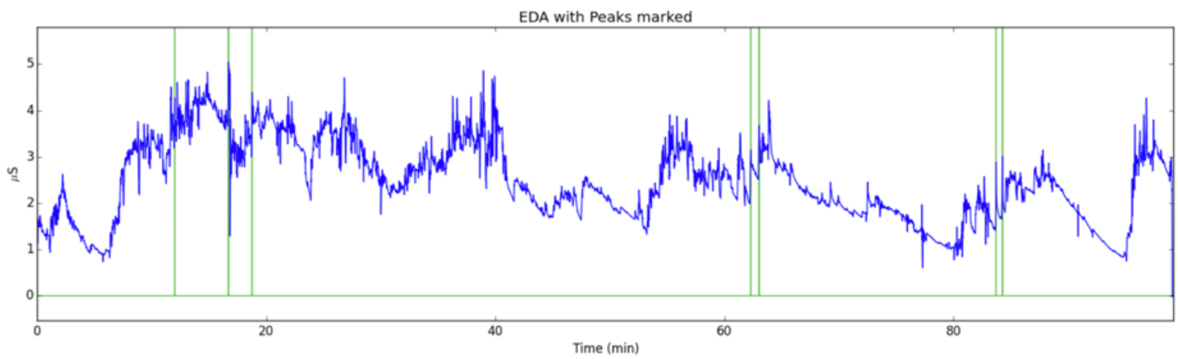

Figure 2. Sample EDA data from EDA explorer at an amplitude threshold of 1.0 μS.

As recommended by Lee and colleagues [54], a filter was applied to exclude peaks which did not exceed 1.0 μS, as these readings were considered to be due to low skin conductivity.

Lesson observations. As the school leaders were not comfortable with having their students and teachers video recorded, they only allowed the researcher to take notes from lesson observations. These field notes were used to triangulate the EDA data and results from the STEM-Interest survey to determine student engagement and interest as they participated in the activities, as they provided context into what specific activities may have caused physiological arousal in the students, as recorded through the EDA data. Students' engagement, attention, and interest were obtained from these observations, which were triangulated together with the EDA data as a measure of student interest.

3.4. Research Design

The students in this study were given a pre- and post-survey to measure their interest in STEM subjects, complemented by lesson observations and physiological measures in the form of EDA data. Interest will be measured over the course of the 10-week intervention. Based on the pre-survey and recommendations from the teacher, four students were selected to be given the Empatica E4 wristbands to measure their EDA levels. Over the 10 weeks, the researcher observed the students and took down field notes, with the four students being issued the Empatica E4 wristbands to capture their physiological signals such as EDA and heart rate. The wristbands were handed out to the students at the start of the lesson and collected back at the end of the lesson. The data were then transferred from the wristbands to a secure server via USB and downloaded for analysis.

4. Results

This paper will examine two case studies to demonstrate the possible implication of using physiological data as a measure of interest.

4.1. Case Study 1: Daniel

Despite reporting that he had low interest in STEM topics, Daniel was observed to be attentive and thoroughly engaged throughout all the lessons. He was engaged regardless of the activity being done, from watching a video on the Internet of Things, to hands on activities of coding on the micro:bit, and even when the teacher was simply doing face-to-face teaching with the class. This observation was further supported by the EDA data collected where multiple EDA peaks were recorded in every single lesson, which showed that he had regular segments over the term where there were cognitive and emotional arousal during the lessons. For example, during one lesson when the class was given time to tinker around with the micro:bit to create a logo, Daniel was fully engaged in the activity and was excited to share his logo with his friends.

Daniel was also motivated throughout most of the lessons to complete the tasks given. In the eighth lesson of the term, the teacher posed a challenge for the students to code and create an alarm system using micro:bit. Even though this task was relatively advanced for him, Daniel eagerly took up the challenge and was greatly motivated to try to code the alarm system. Even though he was observed becoming stuck and frustrated and on the verge of giving up, he recovered from that quickly and began trying again. Despite being clearly frustrated, Daniel persevered and kept trying until the teacher intervened to help by altering the task. This showed that there was a deep and intrinsic interest that motivated him to persist in the task despite not being able to complete it successfully.

Regarding the EDA data recorded, Daniel had multiple EDA peaks in all the lessons recorded, with a total of 54 peaks being recorded, which indicated that there were numerous episodes during the lessons that caught his interest. As compared to Alex, who only had four peaks recorded throughout all the lessons, Daniel experienced relatively more instances where his interest was triggered.

Figure 3 shows the EDA recordings for lesson 8, where the students were tasked to create an alarm system. As can be seen, the first peak recorded (1.96 μS) was around the 10-min mark, which was when the teacher explained the task to the class. This shows that Daniel was excited by the task, and was keen to engage in it. The second EDA peak (4.93 μS) was recorded at around the 15-min mark, which was when Daniel began working on the task and was greatly focused on attempting to code the alarm system. This was one out of many examples that indicated Daniel's high level of arousal, and in turn, of interest and excitement toward the tasks and activities in the class.

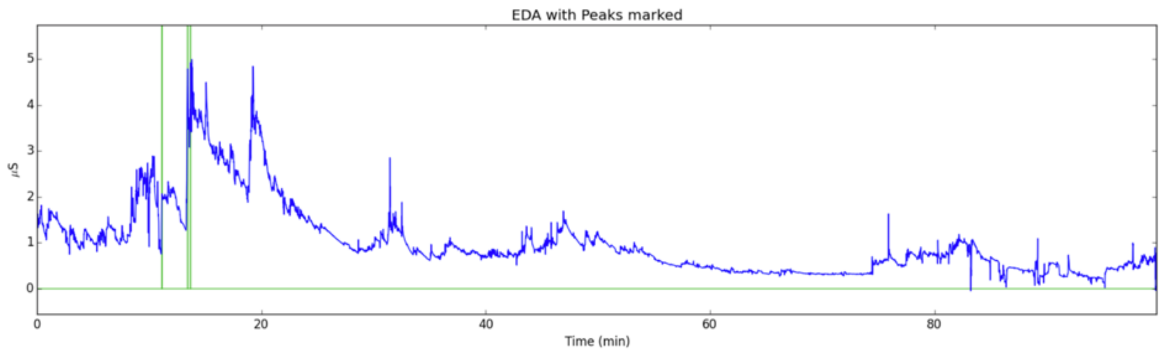

Figure 3. Daniel's EDA peaks recorded in lesson 8.

Based on the STEM Interest Survey results (Table 2), Daniel showed an increase in his mean score, from 2.27 to 3.00 (out of 5), indicating that there was an increase in his interest by the end of the term as compared to at the beginning. A detailed look at the survey questions can provide some insights into Daniel's changing interest toward STEM subjects. One question (Q4) asked "How much fun is math, science, or engineering for you?", to which Daniel initially responded with a "2" during the pre-test, but by the end of the term, his response was a "4" on the post-test. Another question (Q7) asked "How much do you enjoy hands-on activities and experiments in math, science, and engineering subjects?", which appeared to increase from a "3" to a "5" by the end of the term. A possible explanation for this increase could be that as Daniel became more adept in his ability to code using the micro:bit, he gained confidence when given new tasks by the teacher. As he was able to successfully complete increasingly complex tasks, he may have developed a positive outlook toward STEM subjects and gained a deeper interest through this process.

Table 2. STEM Interest Survey results for Daniel.

	S016_Pre	S016_Mid	S016_Post
Q1	3	4	5
Q2	2	3	4
Q3	3	4	4
Q4	2	4	4
Q5	5	2	3
Q6	1	2	2
Q7	3	5	5
Q8	3	4	4
Q9	3	4	4
Q10	3	3	4
Q11	2	2	2
Q12	1	2	1
Q13	1	1	1
Q14	1	1	1
Q15	1	1	1
Mean	2.27	2.80	3.00

Based on Renninger and Hidi's four-phase model of interest [13], Daniel was observed to begin the term at phase one (triggered situational interest) when he was introduced to the various STEM topics. As the term progressed, through the regular re-engagement with the content every lesson, he began to develop content knowledge and eventually progressed to phase two (maintained situational interest). With the stored knowledge, he began to reengage with the content independently, as observed when he was tinkering with the micro:bit whenever the teacher gave the class free time in class, which are traits of an emerging individual interest (phase three). At the end of the term, Daniel not only continued to work independently to constantly reengage with the content, but he was able to persevere through challenges he faced, which marks a well-developed individual interest (phase four).

4.2. Case Study 2: Alex

Alex was observed to be more easily distracted and markedly less engaged as compared to Daniel, despite stating that he had a high interest in STEM subjects. For instance, during the third lesson, when the teacher was showing a video on the Internet of Things to the class, the whole class was observed to be attentive to the video, but Alex appeared uninterested and was staring into space. He behaved in a similar manner when the teacher was engaged in frontal teaching, and at the same time, he was observed to be chatting with friends even while the teacher was talking. However, he was noticeably more engaged during the hands-on activities, where he showed more interest in exploring the micro:bit and its functions. By the end of the term, during Lesson 8, when tasked to create an alarm system, Alex was fully engaged throughout the whole lesson, even without any intervention from the teacher. This was a vast difference compared to his attitude at the start of the term.

Alex appeared to lack motivation during the lessons initially, which can be seen when he simply gave up and reverted to asking his classmates for help when he was unable to manage a task. However, over the term, he became increasingly motivated. By the final lesson of the term, he was on-task for most of the lesson, and when his classmates talked or distracted him, he would ask them to stop fooling around so that he could work on his task.

Alex did not have many EDA peaks recorded over the term, totaling only four peaks, and for the instances that peaks were recorded, they were not directly related to the lesson content. The peaks recorded were when Alex asked his peers for help coding his micro:bit as he was not paying attention to the instructions and when he was fooling around with his friends. However, there was one peak during Lesson 7 that was during a session where the teacher was doing revision with the class for an upcoming test.

Lastly, based on the STEM Interest Survey (Table 3), there was not much change in the total mean score at the end of the term. However, the individual questions are able to provide more nuanced insights into Alex's interest in STEM. Q4 asked "How much fun is math, science, or engineering for you?", which showed a gradual decrease as the term progressed. One possible reason for this decrease could be due to the increasing difficulty of tasks set as the term progressed, which Alex may have found too difficult to complete, and as a result felt that the activities were not as fun. Q7 garnered a consistently high response of "6", to the question "How much do you enjoy hands-on activities and experiments in math, science, and engineering subjects?", which was supported by the lesson observations showing that he was engaged during hands-on activities.

Tracing Alex's interest development journey using the four-phase model of interest development, he began the term at phase one (triggered situational interest), where he was observed to engage with the lesson activities only momentarily and requiring direct instruction from the teacher and support from his peers. Over the term, he was observed to progress to phase two (maintained situational interest), where he began to develop an appreciation of the value of content knowledge. While he still required support from his peers, he developed a more positive disposition toward the lessons. However, by the end of the term, his interest was observed to be maintained at phase two.

Table 3. STEM Interest Survey results for Alex.

	S009_Pre	S009_Mid	S009_Post
Q1	4	4	4
Q2	3	3	5
Q3	5	4	4
Q4	6	5	4
Q5	5	6	6
Q6	5	6	4
Q7	6	6	6
Q8	5	5	5
Q9	4	4	5
Q10	4	4	5
Q11	5	3	5
Q12	5	3	4
Q13	4	4	4
Q14	5	5	4
Q15	4	3	5
Mean	4.67	4.33	4.67

5. Discussion

The study provides an interesting insight into a number of areas. Firstly, it highlights the difference in responses between using a self-report questionnaire and the physiological measure of EDA. The two case studies highlighted both showed that there were different responses between the students' self-report and their EDA readings. For instance, based on the lesson observations, Daniel was found to have a high level of interest in STEM-based subjects, which was in direct contrast with his responses to the survey. This was similar to Alex, who responded in the survey that he was interested in STEM subjects, but whose behavior and EDA readings showed otherwise. One possible explanation was that Alex may have been responding to the survey questions based on what he thinks is an acceptable response for the teacher. Another possible reason could be that students may have interpreted the questions in the survey differently due to factors like memory, beliefs, or pressure from peers, which concurs with prior research [22].

A physiological measure may therefore be able to paint a more accurate picture of student interest as compared to self-report surveys by overcoming limitations from misinterpretation [22], how individuals perceive themselves [23] or simply because they may be unaware of their own interest being triggered [24]. Based on the case studies, the EDA readings more closely mirrored the behavior and reactions of the students during the lessons. For example, Daniel was observed to be highly engaged and motivated throughout the term, which was reflected in his EDA readings, which recorded multiple peaks in all of the lessons. On the other hand, Alex displayed minimal interest and motivation during the lessons, which was reflected in the low number of EDA peaks recorded throughout the term. Compared to the survey results, the EDA readings are able to provide data that are more congruent with what was observed. This is especially so for identifying situational interest, with the EDA peaks being able to determine specific activities causing a spike in their EDA levels, which can be attributed to "triggers" of interest. With a more accurate identification of "triggers" of interest, researchers are able to better recognize specific activities that spark interest and possibly contribute to the development of interest in students. Teachers or curriculum planners are able to utilize these findings to create targeted activities that are of greater interest to students. However, a caveat is that this is based only on two case studies, and though the possibilities appear promising, additional work with a larger sample size and data is needed to generalize these findings to a wider population.

The use of such measures opens up numerous possibilities for using more ecologically valid and non-invasive measures of interest development, which can possibly benefit both researchers and practitioners. The E4 wristbands are easy to operate, requiring the users to simply turn on the wristband and put it on like a watch. The students only took a few short moments to get used to the E4, and they were able to participate in the lesson without any additional restrictions. The data were automatically stored in in the device, and the battery life of up to 32 h will enable data recording for a whole day of school.

Another possible affordance of using EDA as a measure for interest is that it may be able to provide a more objective dimension to qualitative case studies. Rather than the typical measures of observations, video or audio recordings, which may be subject to differing forms of interpretation, the use of EDA may be able to provide a measure that is more unbiased in nature. For example, a student who is completely uninterested in STEM subjects can "fake" a response on a self-report questionnaire, but it would be more challenging to engineer a physiological response, which is different from what is really being felt. The use of physiological measures such as EDA may therefore be able to alleviate the problem of education research being commonly viewed as too subjective in nature and being determined largely by personal beliefs [55].

A significant implication for interest research is in the use of EDA as a novel method for tracking interest. For instance, through the use of the E4 wristband, students are able to wear them for relatively long periods of time, such as throughout a school day. Researchers will thus be able to obtain regular and consistent data on students' arousal toward various stimuli they may have experienced throughout the day. This will provide a rich source of data that can be analyzed at a greater depth, with possible affordances including measuring students' cognitive or emotional arousal throughout the day, providing researchers and practitioners with valuable data on what specific activities or content is able to better engage students. Such information can enable practitioners and curriculum planners to create lessons and activities that better engage students.

Overall, the use of EDA as a measure of interest is a relatively effective method of identifying and possibly tracking interest development. However, it should be noted that a limitation is that currently, EDA readings will still have to be triangulated with behavioral observations in order to contextualize the data. For instance, when a teacher asks a student a question and an EDA peak is recorded, it may mean that the student is either eager to answer, or afraid of being called out to answer the question. The behavioral data recorded would therefore be able to provide more context to interpret such data, which would not make much sense without a given context.

Another limitation and possible future area of research is for the conduct of a controlled laboratory study to obtain a baseline EDA reading of students at rest in order to more accurately differentiate instances of interest or disinterest. Even though the use of the EDA Explorer is able to remove potential noise from the readings captured, every study population may potentially have different EDA baseline levels. The recording of a baseline EDA reading in a controlled laboratory setting will therefore allow us to provide a more accurate reading of the changes in EDA as a result of interest within a specific study population.

Another limitation is that the current study is based on case studies of a small population size. A study with a larger population size would be able to provide a more in-depth analysis of physiological changes during periods of interest, and would be ideal to further validate the effectiveness of EDA as a measure for interest development. A possible direction could be to also trial the use of the E4 bands in a formal academic setting in order to assess student interest for typical school subjects such as mathematics or English, as an alternative manner of assessment of engagement.

6. Conclusions

The findings from the study provide promising insights into the possibilities of using physiological measures to trace student learning and interest development by introducing EDA as a possible indicator for interest. From the preliminary data collected for the study, EDA is found to be a relatively objective and possibly effective measure of interest as compared to the traditional method of self-report surveys. These physiological measures are more adept at meeting the demands of more personalized and targeted trajectories of learning and assessment, offering a more nuanced and possibly more illuminating method of understanding how and why humans take interest in certain subjects but not others, and through this process, cultivate the value of lifelong learning.

Author Contributions: Conceptualization, A.L.T., R.G. and A.J.; methodology, A.L.T., R.G. and A.J.; formal analysis, A.L.T.; investigation, A.L.T.; data curation, A.L.T.; writing—original draft preparation, A.L.T.; writing—review and editing, A.L.T., R.G. and A.J.; supervision, R.G. and A.J.; project administration, A.L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the University of Queensland (Approval number: 2018002401, date of approval: 3 May 2019).

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.

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

References

1. Bandura, A. Perceived self-efficacy in cognitive development and functioning. *Educ. Psychol.* **1993**, *28*, 117–148. [CrossRef]
2. Amrein, A.L.; Berliner, D.C. The effects of high-stakes testing on student motivation and learning. *Educ. Leadersh.* **2003**, *60*, 32–38.
3. Johnson, D.D.; Johnson, B.; Farenga, S.J.; Ness, D. *Stop High-Stakes Testing: An Appeal to America's Conscience*; Rowman Littlefield Publishers, Inc.: Washington, DC, USA, 2008.
4. Fredrickson, B.L.; Branigan, C. Positive Emotions. In *Emotions*; Mayne, T.J., Bonanno, G.A., Eds.; Guilford: New York, NY, USA, 2000; pp. 123–151.
5. Krapp, A. Interest and human development: An educational-psychological perspective. *Br. J. Educ. Psychol. (Monogr. Ser. IIPart 2)* **2003**, *2*, 57–84.
6. Hidi, S.; Renninger, K.A. The four-phase model of interest development. *Educ. Psychol.* **2006**, *41*, 111–127. [CrossRef]
7. Renninger, K.A.; Ewen, L.; Lasher, A.K. Individual interest as context in expository text and mathematical word problems. *Learn. Instr.* **2002**, *12*, 467–491. [CrossRef]
8. 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]
9. Renninger, K.A.; Hidi, S. Revisiting the conceptualization, measurement, and generation of interest. *Educ. Psychol.* **2011**, *46*, 168–184. [CrossRef]
10. Hidi, S.E.; Ainley, M. Interest and Self-Regulation: Relationships between Two Variables that Influence Learning. In *Motivation and Self-Regulated Learning: Theory, Research, and Application*; Schunk, D.H., Zimmerman, B.J., Eds.; Erlbaum: Mahwah, NJ, USA, 2008; pp. 77–109.
11. Schank, R.C. Interestingness: Controlling inferences. *Artif. Intell.* **1979**, *12*, 273–297. [CrossRef]
12. Schiefele, U. Interest, learning and motivation. *Educ. Psychol.* **1991**, *26*, 299–323.
13. Renninger, K.A.; Hidi, S.E. *The Power of Interest for Motivation and Engagement*; Routledge: New York, NY, USA, 2016.
14. Black, A.E.; Deci, E.L. The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Sci. Educ.* **2000**, *84*, 740–756. [CrossRef]
15. Firat, M.; Kilinc, H.; Yuzer, T.V. Level of intrinsic motivation of distance education students in e-learning environments. *J. Comput. Assist. Learn.* **2018**, *34*, 63–70. [CrossRef]
16. Jack, B.M.; Lin, H.-S. Igniting and sustaining interest among students who have grown cold toward science. *Sci. Educ.* **2014**, *98*, 792–814. [CrossRef]
17. Ainley, M.; Hidi, S.; Berndorff, D. Interest, learning, and the psychological processes that mediate their relationship. *J. Educ. Psychol.* **2002**, *94*, 545–561. [CrossRef]
18. Hidi, S. Interest: A unique motivational variable. *Educ. Res. Rev.* **2006**, *1*, 69–82. [CrossRef]
19. Rotgans, J.I.; Schmidt, H.G. Situational interest and learning: Thirst for knowledge. *Learn. Instr.* **2014**, *32*, 37–50. [CrossRef]
20. Pintrich, P.R.; Smith, D.; Garcia, T.; McKeachie, W. *A Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ)*; The University of Michigan: Ann Arbor, MI, USA, 1991.
21. Mazer, J. Development and Validation of the Student Interest and Engagement Scales. *Commun. Methods Meas.* **2012**, *6*, 99–125. [CrossRef]
22. 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.

23. 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]
24. Renninger, K.A.; Bachrach, J.E. Studying triggers for interest and engagement using observational methods. *Educ. Psychol.* **2015**, *50*, 1–12. [CrossRef]
25. Gruart, A. The role of neurosciences in education and vice versa. *Int. J. Educ. Psychol.* **2014**, *3*, 21–48.
26. Zembylas, M.; Charalambous, C.; Charalambous, P. The schooling of emotion and memory: Analyzing emotional styles in the context of teacher's pedagogical practices. *Teach. Teach. Educ.* **2014**, *44*, 69–80. [CrossRef]
27. Morris, J.; Sah, P. Neuroscience and education: Mind the gap. *Aust. J. Educ.* **2016**, *60*, 146–156. [CrossRef]
28. Cowley, B.; Filetti, M.; Lukander, K.; Torniainen, J.; Henelius, A.; Ahonen, L.; Jacucci, G. The psychophysiology primer: A guide to methods and a broad review with a focus on human-computer interaction. *Found. Trends Hum. -Comput. Interact.* **2016**, *9*, 151–308. [CrossRef]
29. Zhang, Y.; Qin, F.; Liu, B.; Qi, X.; Zhao, Y.; Zhang, D. Wearable neurophysiological recordings in middle-school classroom correlate with students' academic performance. *Front. Hum. Neurosci.* **2018**, *12*, 1–8. [CrossRef]
30. Wu, C.; Huang, Y.; Hwang, J. Review of affective computing in education/learning: Trends and challenges. *Br. J. Educ. Technol.* **2016**, *47*, 1304–1323. [CrossRef]
31. Bouscein, W. *Electrodermal Activity*, 2nd ed.; Springer Sciences Business Media: Berlin, Geramny, 2012.
32. Dawson, M.E.; Schell, A.M.; Filion, D.L. The Electrodermal System. In *Handbook of Psychophysiology*, 4th ed.; Cacioppo, J.T., Tassinary, L.G., Berntson, G.C., Eds.; Cambridge University Press: Cambridge, UK, 2016; pp. 217–243.
33. Cacioppo, J.T.; Tassinary, L.G.; Bernston, G.G. *Handbook of Psychophysiology*, 3rd ed.; Cambridge University Press: Cambridge, UK, 2007.
34. Critchley, H.D. Electrodermal responses: What happens in the brain. *Neuroscientist* **2002**, *8*, 132–142. [CrossRef]
35. Kucher, K.; Cernea, D.; Kerren, A. Visualizing Excitement of Individuals and Groups. In Proceedings of the 2016 EmoVis Conference on Emotion and Visualization, Sonoma, CA, USA, 10 March 2016; pp. 15–22. Available online: http://www.ep.liu.se/ecp/103/003/ecp16103003.pdf (accessed on 20 May 2021).
36. Cain, R.; Lee, V. Measuring Electrodermal Activity to Capture Engagement in an Afterschool Maker Program. In Proceedings of the 6th Annual Conference on Creativity and Fabrication in Education, Stanford, CA, USA, 14–16 October 2016; pp. 78–81.
37. Bailey, A.W.; Johann, J.; Kang, H.K. Cognitive and physiological impacts of adventure activities: Beyond self-report data. *J. Exp. Educ.* **2017**, *40*, 153–169. [CrossRef]
38. Gillies, R.M.; Carroll, A.; Cunnington, R.; Rafter, M.; Palghat, K.; Bednark, J.; Bourgeois, A. Multimodal representations during an inquiry problem-solving activity in a year 6 science class: A case study investigating cooperation, physiological arousal and belief states. *Aust. J. Educ.* **2016**, *60*, 111–127. [CrossRef]
39. Valenza, G.; Scilingo, E.P. *Autonomic Nervous System Dynamics for Mood and Emotional-State Recognition: Significant Advances in Data Acquisition, Signal Processing and Classification*; Springer International Publishing: Cham, Switzerland, 2014.
40. Pijeira-Díaz, H.J.; Drachsler, H.; Kirschner, P.A.; Järvelä, S. Profiling sympathetic arousal in a physics course: How active are students? *J. Comput. Assist. Learn.* **2018**, *34*, 397–408. [CrossRef]
41. Yoshida, R.; Sakai, T.; Ishi, Y.; Nakayama, T.; Ogitsu, T.; Mizoguchi, H. Electrodermal activity-based feasibility study on the relationship between attention and blinking. *Int. J. Smart Sens. Intell. Syst.* **2016**, *9*, 21–31. [CrossRef]
42. Daily, S.B.; James, M.T.; Roy, T.; Darnell, S.S. Engageme: Designing a visualization tool utilizing physiological feedback to support instruction. *Technol. Instr. Cogn. Learn.* **2015**, *10*, 107–126.
43. Di Lascio, E.; Gashi, S.; Santini, S. Unobtrusive assessment of students' emotional engagement during lectures using electrodermal activity sensors. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* **2018**, *2*, 1–21. [CrossRef]
44. Setz, C.; Arnrich, B.; Schumm, J.; La Marca, R.; Troster, G.; Ehlert, U. Discriminating stress from cognitive load using a wearable EDA device. *IEEE Trans. Inf. Technol. Biomed.* **2010**, *14*, 410–417. [CrossRef]
45. Picard, R.W.; Fedor, S.; Ayzenberg, Y. Multiple arousal theory and daily-life electrodermal activity asymmetry. *Emot. Rev.* **2016**, *8*, 62–75. [CrossRef]
46. Poh, M.Z.; Swenson, N.C.; Picard, R.W. A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE Trans. Biomed. Eng.* **2010**, *57*, 1243–1252. [PubMed]
47. Van Dooren, M.; de Vries, J.J.G.G.-J.; Janssen, J.H. Emotional sweating across the body: Comparing 16 different skin conductance measurement locations. *Physiol. Behav.* **2012**, *106*, 298–304. [CrossRef]
48. 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. Dissertation, University of Queensland, St. Lucia, QLD, Australia, UQ eSpace. 2021. Available online: https://espace.library.uq.edu.au/view/UQ:2dadff9 (accessed on 12 May 2021).
49. Anderson, T.; Shattuck, J. Design-based research: A decade of progress in education research? *Educ. Res.* **2012**, *41*, 16–25. [CrossRef]
50. 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]
51. Renninger, K.A.; Schofield, L.S. Assessing STEM Interest as a Developmental Motivational Variable; *Poster presented at American Educational Research Associa-tion*. **2014**, in press.
52. Empatica. 2021. Available online: https://www.empatica.com/research/e4/ (accessed on 15 May 2021).

53. Taylor, S.; Jaques, N.; Chen, W.; Fedor, S.; Sano, A.; Picard, R. Automatic identification of artifacts in electrodermal activity data. Presented at the 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, Italy, 25–29 August 2015.
54. Lee, V.R.; Fischback, L.; Cain, R. A wearables-based approach to detect and identify momentary engagement in afterschool Makerspace programs. *Contem. Educ. Psych.* **2019**, *59*, 1–15. [CrossRef]
55. McWilliam, E.; Lee, A. The problem of "the problem with educational research". *Aust. Educ. Res.* **2006**, *33*, 43–60. [CrossRef]