Psychophysiological methods to study the triggers of interest: A Singapore case study

Introduction

Interest is an essential motivational component that plays a significant role in learning (Renninger & Hidi, 2011). When individuals are interested in something, they will perceive the process of learning as something enjoyable. In this vein, interest has been described as a motivational belief and passion for learning (Hidi & Ainley, 2008), and as such it is something that is intrinsic and can enable individuals to pursue and persevere in the acquisition of knowledge without any external influence. It is therefore important for both researchers and practitioners to have a better understanding of how interest is, or can be, triggered in order for it to develop into a more developed and productive form of interest. However, most studies of interest have historically relied on self-report measures, with participants being unable to provide a full and accurate reporting on the triggering process of interest. This is particularly due to the fact that triggers of interest are characteristically unexpected and fleeting, meaning that individuals may not realise that their interest has been triggered (Renninger & Bachrach, 2015). Despite the fact that observational studies are able to provide rich contextual detail on learners' experiences when they engage in a learning activity highlighting varying levels of engagement in learning contexts (Fredericks & McColskey, 2012), limited studies have been done using observational data to examine the triggering process of learners. This paper therefore aims to investigate how interest is triggered using observational methods and psychophysiological measures from a case study analysis of data collected from four students involved in a 10-week coding in-school programme.

Literature review

Framing interest development in learning

Interest has been found to be an antecedent to focused attention, enhance sustained engagement, develop positive affect, and helps to consolidate understanding of content (Crouch et al., 2018). It is also able to optimise learning and engagement by enabling learners to solve challenging problems, set goals, self-regulate behaviours (Sansone et al., 2012) and increased the use of cognitive strategies (Patall et al., 2016). A study by Tan and colleagues (2021) also found that interest led to an improvement to the quality of learning as students were more self-motivated to engage in tasks, and were observed to experience more positive emotions.

Interest has been described as the psychological state of a person engaging with a specific content, and the cognitive and motivational tendency to reengage with the specific content over time (Renninger & Hidi, 2016). Renninger and Hidi (2011) highlighted five characteristics of interest. First, interest is content specific and always occurs with respect to specific objects or ideas. Second, interest involves the interplay of both cognitive and affective components, which shifts together with development of interest. This means that as knowledge develops, valuing and feelings toward the content are enriched. Third, interest is malleable and develops relative to the learning environment. The learning environment includes support from teachers and/or peers, characteristics of learning tasks, and the culture of the community. Fourth, individuals may not always be conscious of the interest triggering process, due to no expectation of interest developing or because they may be too caught up in the flow of the activity of interest to realise their interest was triggered. Lastly, interest has a neurological foundation of which individuals have a desire to reengage with content of interest over time in order to obtain deeper understanding.

In education research, interest has also been described as an antecedent to engagement over time and have been defined into two distinct forms of interest: situational interest and individual interest

(Hidi & Renninger, 2006). Situational interest is defined as a psychological state of interest triggered by specific environmental stimuli in the moment of engagement (Hidi & Renninger, 2006; Jack & Lin, 2014), whereas individual interest is a relatively stable tendency to re/engage with the content of interest (Hidi & Renninger, 2006; Krapp, 2002). Therefore, even though triggered interest is ephemeral, it has the potential to develop into a more developed and persistent form of interest which will lead to a more productive participation in activities and learning (Mitchell, 1993; Renninger & Bachrach, 2015). This dichotomy of interest eventually developed to the currently well-known Four Phase Model of Interest Development (Hidi & Renninger, 2006). This model provides comprehensive descriptions of the four developmental stages of interest, the impact of environmental factors on interest, and the relationship between the individual and content (Fryer, 2019). The Four Phase Model of Interest Development depicts how interest develops over four stages (Hidi & Renninger, 2006; Hidi & Renninger, 2019; Renninger & Hidi, 2016):

1. Triggered situational interest: Occurs primarily due to environmental influences involving actual content matter, typically related to strong affective experiences.
2. Maintained situational interest: Interest can be sustained through personally meaningful tasks (no longer solely supported by environment), more persistent and focused attention, continued growth of knowledge and value.
3. Emerging individual interest: Beginning of a more enduring form of interest. May independently reengages with content and seeks out information. Generally positive affect but may require support and encouragement to persevere through more challenging tasks.
4. Well-developed individual interest: Independently reengages content, positive feelings, can self-generate interest without external support, and able to persist in face of challenge.

Interest needs to be sustained through regular and deep engagement, or it may remain stagnant, regress, or even vanish completely (Maltese & Harsh, 2015; Renninger & Hidi, 2016). It is therefore important for learners to have access to support and opportunities to constantly engage with the content of interest in order for their interest to progressively develop. This paper will focus on situational interest, particularly triggered situational interest and its specific triggers in a learning environment. For instance, in a classroom context, situational interest can potentially be triggered by teachers who encourage students to develop their own learning goals and by creating the space for students to strive toward them (Rotgans & Schmidt, 2011).

However, it should be highlighted that interest is content specific. This means that it cannot be assumed that learners interested in a subject (e.g. physics), would be interested in all subject-related content (Renninger & Hidi, 2020). For example, they may only be interested in a particular topic, such as heat, but may not have an interest in other physics- related topics such as electricity. Having an understanding of the phases of interest development will therefore enable teachers to deploy the appropriate tasks in order to increase the learners' interest (Fryer, 2019), and expand that interest from content specific to a more general form of interest toward the whole subject. For instance, if a learner has little or no interest in a topic, the first course of action should be to trigger their interest through interesting activities or videos. As the learner's interest develops and progresses through the phases, the method of instruction should shift toward making the content meaningful for the learner in order to increase their stored knowledge and value. Teaching a subject in a wide variety of ways and involving students in the learning process while providing consistent and sufficient support can enable interest to develop (Xu et al., 2012). However, it may be impossible for teachers constantly personalise every instructional activity for every student due to limited time and resources. Recognising and adjusting instructional practice to engage students with varying interests can therefore be a starting point to support interest development on a class-wide level. Open-ended tasks and activities can comprise of interest triggers that allow those with a lesser developed form of interest to make associations to the specified content, and to afford those with a more-developed form of interest to expand their understanding and make added meaningful associations (Renninger & Hidi, 2020).

It is therefore important for both practitioners and researchers to obtain a better understanding of the triggering process in order to better adapt the learning environment or instructional methods to trigger and sustain interest in students.

Triggers of interest

As alluded above, earlier phases of interest development has primarily external triggers of interest, such as from tasks or activities, with triggers becoming more internal and self-generated such as due to an individual's own curiosity. Furthermore, research has shown that there is evidence highlighting that the presence of a responsive educator, together with a suitable environment facilitates learner engagement (Fredericks, 2014; Pressick-Kilborn, 2015), and in the process offering potential "trigger points" for interest. A deeper understanding of how learners respond to the various types of activities will help researchers better understand and express the relationship between the triggering process and its context (Renninger & Bachrach). Dohn (2013) hypothesised situational interest to stem from challenge of a task, social interaction among peers, and situational stimuli inherent in the learning context. He also highlighted observable indicators of interest, which include attention to the task, focus, length of time spent on task, expression of a desire to revisit ideas, and expressed positive affect. Some examples of triggers of interest include using novel or surprising task features to introduce new materials to students (Nieswandt & Horowitz, 2015), involving learners to work together on open-ended group projects that support from peers (Knogler et al., 2015), or personalising content (Bernacki & Walkington, 2018). In their study, Renninger and Bachrach (2015) identified eight triggers of interest based on research literature and their observational records: challenge, autonomy, group work, computers/technology, instructional conversation, hands-on activity, novelty, and personal relevance. These eight triggers will be used as an initial list of triggers to describe the triggers observed in the current study. They also stated that it will be useful to know whether individuals are engaged cognitively, behaviourally and/or affectively. With the developments in psychophysiological technology and measures being made available, the measure of arousal will be able to complement observational data to provide an added dimension from the physiological perspective.

Electrodermal activity: A novel measure of interest

Electrodermal activity (EDA) refers to the bodily response resulting in variations in the electrical conductance levels of the skin, and is made up of two components: rapid fluctuations known as skin conductance responses (SCR), and slower changes in the skin conductance level (SCL) (Dawson et al., 2016). Of interest is the SCR, which occur as a result of the body's reaction to a stimulus at the immediate point of time (Cacioppo et al., 2007). What this means is that through the tracking and measurement of SCR, it is possible to measure the type and duration of an activity which caused the response (Tan et al., 2021). The skin is densely innervated with eccrine sweat glands that are manifested in fluctuations in electrodermal activity levels measurable on skin (Critchley, 2002). Electrodermal activity is stimulated by the moisture generated from the sweat glands, and occurs involuntarily as a result of arousal (Kucher et al., 2016). These changes in skin conductivity can therefore be captured as EDA recordings using suitable sensors.

EDA is typically measured at the palms and fingers of the hands, where there is the highest concentration of sweat gland density (Setz et al., 2010). Electrodes are then applied to these areas with gels, followed by the application of a current in order to obtain EDA readings, measured in microSiemens (µS). Much of the initial EDA research were conducted in controlled laboratory settings, due to the tendency of the gels to wear off over time, resulting in the recording of inaccurate signals (Picard et al., 2016). Over time, technological advancements have made the use of such physiological equipment more practical in the form of wearable technology, providing more ecological affordances such as in real-time classroom settings. Studies have been conducted (Poh et al., 2010; van Dooren et al., 2012), and have validated the use of wearable devices on the wrist to be a viable method of measuring EDA, with data being found to be significantly correlated with EDA data captured at the fingers.

Several studies have used EDA as a measure of tenets of learning, such as cognitive and affective arousal (Bailey et al., 2017; Gillies et al., 2016; Valenza & Scilingo, 2014), increased attention (Yoshida et al., 2016), interest and engagement (Cain & Lee, 2016; Tan et al., 2021). Studies have also found positive correlations between academic performance and EDA (Zhang et al., 2018). A study has also found a particularly significant increase in physiological arousal, as measured through EDA, as a result of situational interest (Cain & Lee, 2016). EDA have therefore been used as a measure in various contexts of learning, with engagement and interest being one possible area.

Methodology

Context and participants

The current study was conducted in a specialised high school that offers a variety of vocational subjects such as retail management, robotics, apart from the typical academic subjects like mathematics and science. The school and its teachers strongly believes in cultivating the joy of learning, and as such, the teachers strive to cultivate interest and joy in learning through their lessons and learning environment. The participants in the study were from a class of 22 secondary 1 (13 years old), consisting mainly of boys, with seven girls (32%), who gathered once a week for two hours for the lesson. Four students were given the Empatica E4 device to wear during the lessons based on their interest level in STEM, as well as their aptitude in STEM subjects, as recommended by the teacher (Table 1). Their interest in STEM was measured by the STEM Interest Survey (described in the “Measures” section below). As the students were in secondary 1, they have yet to undertake any assessment in the current school. Their aptitude in STEM was therefore determined by their primary school results which the teacher provided. The current students were selected based on students’ with the highest and lowest levels of STEM interest first, followed by their aptitude in STEM.

Table 1.

Students given the E4 device

Name (Pseudonym)	**Interest and Aptitude**
Tyler	Low interest, High aptitude
James	High interest, Low aptitude
Ethan	Low interest, Low aptitude
David	High interest, High aptitude

Tyler is a 13 year old male student with a cheerful disposition. He was observed to be smiling often, with a positive attitude in class. He was also helpful to his peers in that whenever he completed the set tasks earlier, he would assist his classmates who were struggling with their tasks. James is a 13 year old male student who had a playful disposition, occasionally making good-humoured remarks with his peers. He is observed to enjoy interacting with his peers, and was occasionally caught watching YouTube videos during tinkering time. Ethan is a 13 year old male student who had a gentle and meek disposition who was observed to frequently be lost in his thoughts. He would occasionally interact with his peers, but mostly kept to himself during lesson time. David is a healthy 13 year old male student. He presented as a meek student who was generally quiet in class, who occasionally became more excitable whenever one of his classmates was present whereby they would engage in conversations and play pranks on one another.

The teacher worked closely with the first author to develop a series of 10 STEM (Science, Technology, Engineering, and Mathematics) lessons using the a handheld programmable computer tool, micro:bit, to introduce coding in an entertaining manner (https://microbit.org). Each lesson typically consisted of three segments where the teacher would first introduce the theoretical concepts through instructional teaching and videos, followed by discussions to foster interaction among peers and with the teacher, and lastly, a hands-on segment where students will program the micro:bit. The teacher facilitated the activities for all of the lessons. After each lesson, the researcher would have a short debrief on what went well and what was observed during the lesson.

The data of this paper is part of a larger PhD study investigating how interest-driven learning affects students' learning outcomes and interest development. All subjects have provided 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).

Curriculum outline

The 10-week curriculum took place once a week for two hours each session. The sessions were planned such that it is a formulative process whereby the students will first learn basic STEM concepts such as basic circuitry and programming, leading up to the final session where the students will make use of the accumulated knowledge to tackle a task. The first session covered basic safety and wellbeing of individuals in a lab/learning space, including safety practices in the workspace. The second session then provided students with an introduction to the basics of electricity, such as the differences between a direct current and alternating current, and the different types of common circuits used. The third session introduced the students to the concept of Internet of Things, exposing them to the importance and impact of the Internet in the current digital climate. The students were then given a short quiz to gauge students' knowledge from the previous three sessions. The fifth session introduced the students to the micro:bit. During this session, the students learnt about the various components of the micro:bit, and how to program and transfer code from their laptops to the micro:bit itself. The sixth session involved the students learning to code their micro:bits to flash the LED lights in various patterns. The seventh session was then used to conduct a practical assessment for the teacher to gauge the students' knowledge on the basics of coding and use of micro:bit. The eighth session was used as a time for students who missed their assessment to take it, while the rest of the class was able to tinker and explore the micro:bit further. The ninth session introduced students to the possibility of using radio frequency to enable micro:bits to communicate with other micro:bits, and to introduce students to the temperature sensor module of the micro:bit. The tenth and final session was a culmination of what the students have learnt, and required the students to work in groups to create a temperature alarm using their micro:bits.

Measures

This paper used data obtained from observational records in the form of field notes, as well as EDA data recorded using the Empatica E4 device. A STEM Interest survey, adapted from the STEM Tipping Point Survey (Renninger &Schofield, 2014), was administered to identify students' levels of interest before, during and after they participated in the 10-week curriculum. This was used to identify the four students who will be wearing the Empatica E4 devices.

Empatica E4 devices were placed on four students to obtain physiological data while they were engaged in the activities. These devices were worn on the students' non-dominant wrist to reduce the noise generated from excessive movements. As the devices were worn like a watch, it was relatively non-invasive, which allowed the students to participate in the lesson, especially the hands-on tasks, in a natural manner without any inconvenience.

Field notes were recorded during every lesson, which documented the interactions between the teachers and students, students with their peers, how students responded to the lesson activities, and any other observable behaviours such as affect and engagement. During the sessions, the researcher observed the lesson and made field notes on students' interactions with their peers and with the activities, taking note of the students' behaviours and emotions over the course of the sessions. This was done to gather as much contextual information of the class as possible. The students' emotions observed were determined using the circumplex model of affect (Russell, 1980) which categorised observed emotions depending on their valence (i.e. positive or negative emotions) and intensity, determined by the EDA data. These observational data were then triangulated with the EDA data to determine the context and environmental factors which caused the physiological response.

Research design

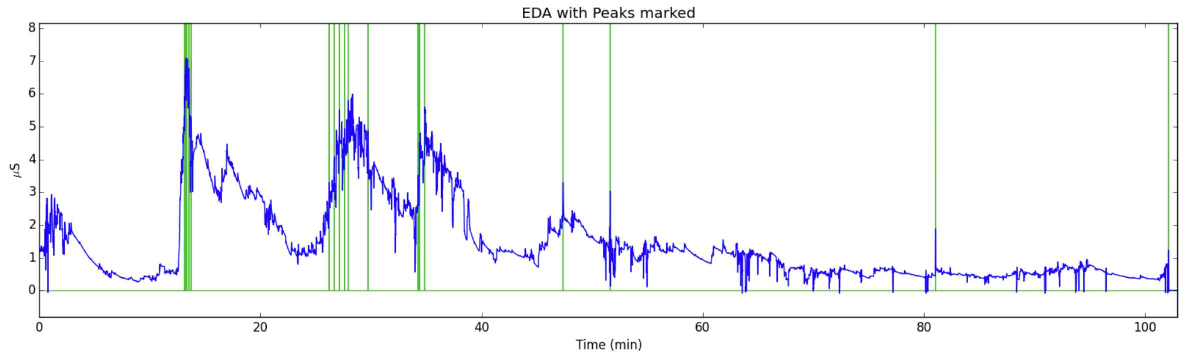
The larger study was designed to determine the impact of interest-driven learning on students' interest development in a STEM-based curriculum. Over the 10-week period, the first author observed the lessons and recorded field notes. The students were handed the Empatica E4 devices at the beginning of the lessons, and they were returned to the researcher at the end of the sessions. The devices were only handed out to the students from Lesson three onwards at the request of the teacher, as he wanted the students to gradually assimilate the researcher in their class before placing the device on the students. As a result, no EDA data were recorded for lessons 1 and 2. The devices were then cleaned and sanitised before the data were transferred and synced to Empatica's secure cloud. At the end of each session, the teacher and researcher had a debrief to determine how the lessons went, and any observations made. Throughout the lessons, the researcher also had informal conversations with the students to gain a more in-depth perspective of their experiences in the activities.

Analysis and findings

The *EDA Explorer* platform was utilised to detect peaks in the EDA data collected, which would signify increased arousal, which could account for triggered situational interest. For the EDA readings to be recorded as peaks, the amplitude had to be of at least 1.0 µS in value, with a 1 second delay. This means that the readings recorded would have to continually increase for at least 1 second before a peak, and continually decrease for 1 second after a peak is detected in order to be recorded as peaks, which were marked by vertical lines (Figure 1). Peaks which did not exceed 1.0 µS were excluded as they were concluded as due to low skin conductivity (Lee et al., 2019).

Figure 1.

Sample of Tyler's EDA Data at Amplitude Threshold of 1.0 µS



Once the peaks were identified, the field notes were reviewed to identify and obtain more details on the specific activities the students were engaged in that led to the peaks in their EDA levels.

Tyler was observed to be generally engaged and interested throughout the lessons, and across various types of activities. These findings were also supported by the EDA data, which identified multiple peaks across most of the sessions. Table 2 shows an overview of the triggers experienced by each student that occurred in each lesson, as recorded via EDA peaks in conjunction with observational data.

Table 2.

Overview of potential triggers

	Autonomy	Challenge	Technology	Group work	Hands-on activity	Instructional conversation	Novelty	Personal relevance
Lesson 3		T	T		T	T	T	
Lesson 4		D	T		T	T/E		T
Lesson 5	T	T	T		T			T
Lesson 6		T/J/E	T/J/E	T	T/J/E		T/E	T
Lesson 7		T				T/J/E		T/J/E
Lesson 8	T	T	T	T	T		T	T
Lesson 9	T/E		T/E		T/E	T	T/E	T
Lesson 10	T	T	T	T	T	T	T	T

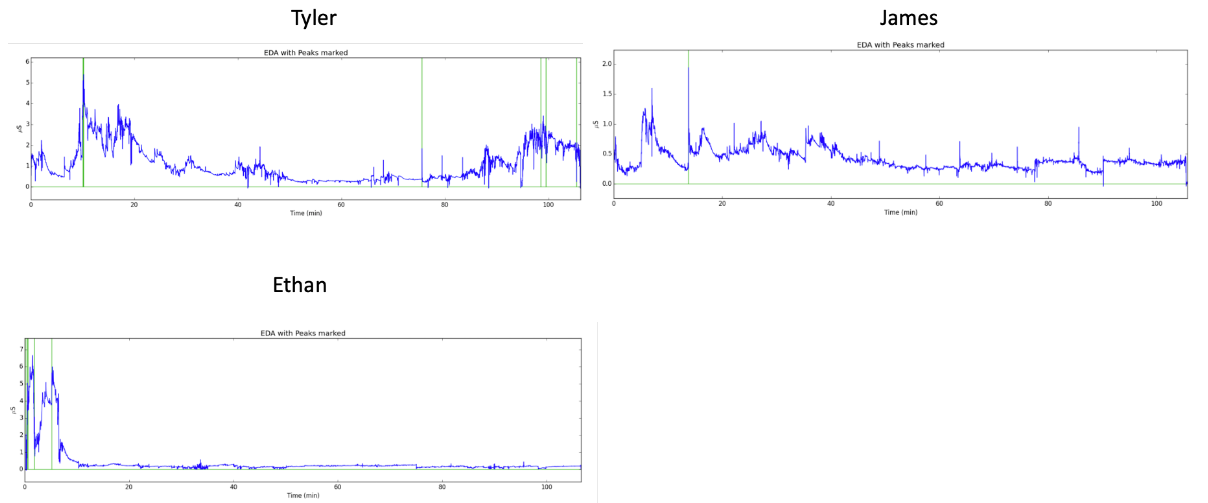
Key: T: Tyler, J: James, E: Ethan, D: David

Multiple triggers of interest were recorded in all the sessions across the three students, with triggers mostly from challenge, technology, and hands-on activity. However, Tyler recorded the most triggers out of the three, in particular for triggers of personal relevance, which were instances when he made connections between the lesson activities and prior experiences such as something that was learnt in a previous lesson, another subject, or something outside school. As the tasks were formative in nature, building on previous lessons' content, the students would have been able to form connections between the various tasks and knowledge learnt as the semester progressed, increasing the personal relevance of what was learnt. Other than that, interest was also triggered when the teacher made connections to topics such as the latest games or day-to-day items such as air-conditioning at home (when talking about the temperature system task). However, it is of interest to note that only Tyler was observed to have triggers of personal relevance throughout the lessons, whereas James and Ethan only had their interest triggered during Lesson 7, which was when the teacher was doing revision with the class.

In this study,hands-on and technology triggers occurred in tandem as the programming of the micro:bit involved the use of laptops to firstly input the code before loading the code into the micro:bit itself. Interest was triggered by technology when the instructions were clear, manageable, and sufficiently challenging. For example, whenever the activities given were either too simple or too challenging, the students became disengaged and ended up surfing the Internet, watching videos online or playing games on the computer. At these times, interest was not triggered. Lesson 6 involved the introduction of additional components to the micro:bit to activate various functions, which added a layer of complexity and challenge. This was a trigger point of interest for all three students when the teacher was introducing this new concept to the class at the start of the lesson (Figure 2).

Figure 2

Lesson 6 EDA Data of students



Other than that, Tyler's interest was triggered whenever there were opportunities for him to tinker with the micro:bit, providing him the autonomy to decide on what to do and explore, such as in lessons 8, 9 and 10. Even though lesson 8 and 9 required the students to complete a set task of designing an alarm system with the micro:bit, they were given the freedom to tackle the task in any way possible based on their knowledge or research. This was interesting, as despite having a specified goal set by the teacher (e.g. to create an alarm system), interest was triggered as Tyler had the autonomy to decide how to go about approaching the goal. Along the way, he also approached other peers for advice, or to have discussions on how to achieve that goal, leading to the spontaneous trigger by group work as well. Ethan had a similar trigger of autonomy when the class was given the freedom to research and implement ways to code the micro:bit to create a temperature sensor.

The students' interest was also triggered whenever they faced a challenging task, and is especially so for Tyler when he managed to overcome these challenges. The lessons involved a myriad of activities such as programming a temperature measurement system or alarm system using various components. These activities provided the students with sufficient challenge as they were required to use the knowledge they had acquired together with additional creativity to think outside the box, in order to successfully complete those systems. EDA peaks were also recorded when Tyler successfully programmed the micro:bit to become a temperature sensor, in which he was observed to be excited and filled with joy when he successfully did it. However, it was observed that when the task was insufficiently challenging, interest was most unlikely to be triggered. In such instances, Tyler was also observed to lose interest in the lesson until the next task was given. It is also of interest to note that in such instances when Tyler lost interest in the lesson because he completed the task quickly, he appeared to be unfocused and disengaged for a significant part of the remainder of the lesson. It was observed that for James and Ethan, other than Lesson 6, there were no triggers of interest due to “challenge”. This could be due to the difficulty in understanding the new concepts being taught, and as a result, they may not feel confident in tackling the tasks leading them to feel indifferent or unenthused about the new tasks.

Tyler’s interest was triggered whenever there were group activities, such as when he and two other classmates were tasked with programming the alarm system, or when they were tasked with working on a presentation to present to the class how they managed to program the micro:bit. During those times, he was observed to be very focused on his task, such as having discussions with his groupmates, doing research, or in the actual programming. His interest was also triggered on occasions where he was seen helping his peers who were stuck on a particular task, or when he asked his classmate to work together with him on a task. During such instances, he was observed to have a generally positive affect such as joy or excitement. This means that group work may sometimes occur as a result of the dynamic social interactions between students, and may not necessarily be something intentionally planned into the lesson. However, it should be noted that group work may not always lead to a trigger of interest. On some occasions, Tyler was seen simply chatting with friends, and may not be a task associated with coding or STEM topics at all. Even though James and Ethan also participated in the group discussions and activities, no EDA peaks were recorded during those instances.

Tyler was observed to be keen to learn in every lesson. From lesson 3, his interest was first triggered when the class finished watching a video that provided an introduction to the Internet of Things, and when the teacher was going through some of the key points from the video. It was triggered again when the teacher asked some students to answer some questions related to the video on the board. Even though he was not called to answer, an EDA peak was recorded while Tyler was engaged with eyes fixed on the students answering the questions on the board. The last activity was when the teacher tasked the students to have a go at creating a code using the micro:bit’s software program MakeCode. This was a novel and slightly challenging experience for Tyler, and he was observed to be thoroughly engaged and enjoying himself during this activity.

Tyler’s interest in learning more about the STEM-related topics was evident in lessons 4 and 7, where the teacher was going through revision on the prior concepts learnt. Even though it was more instructional conversation in nature, whereby the teacher was going through content using the board and PowerPoint slides to foster discussion and responses from the class, Tyler’s interest was triggered both times, and he was observed to be paying full attention to the teacher as well. This also occurred a number of times when he was observed to be paying close attention to the teacher who was giving instructions on the upcoming tasks. James and Ethan also had their interest triggered during lesson 7, where the teacher was revising concepts and having discussions with the whole class. It was observed that in the later half of the term, James began to pay more attention when the teacher was teaching, which was because he began to find some meaning in what was learnt in class and possibly because he was beginning to become concerned about doing well for the subject.

Tyler's interest was triggered by novelty during lessons where a new concept, or function of the micro:bit was taught to the class. Lessons 4, 5 and 7 involved mostly revision or practice on previously learnt codes, as such, no novel experiences or content caught Tyler's attention. The other lessons however, triggered Tyler's interest by novelty through the teaching of new content, introducing new functions of the micro:bit, or by bringing in additional components for the class to connect to the micro:bit. Ethan had his interest triggered due to novelty during lessons 6 and 9 as well, when the students were given novel tasks based on what they were taught that day.

An interesting observation is that David had only one EDA peak recorded during lesson 4, just before the test began. This could be because he may have felt nervous for the upcoming test, which coincided with the behavioural observations, whereby David was observed to be more reserved and nervous. As he has a high interest and high aptitude in STEM, he may not have found the typical activities challenging enough, resulting in a lack of EDA peaks being recorded.

Discussion

This paper provides insights into the affordances of observational records as a measure to study triggers of interest in a classroom environment by providing additional evidence for established theories, as well as providing fresh insights to the study of triggers of interest. The findings from the present study concurs with previous research that there are numerous ways to trigger interest that facilitates their engagement in learning activities (Renninger & Bachrach, 2015), and that triggers seldom occur in isolation (Renninger et al., 2019). Combinations of triggers are also not always planned, as seen in the current case study whereby autonomy led to a spontaneous trigger of group work when Tyler approached his classmates to discuss how best to achieve the task goals. This finding highlights the importance of understanding the triggering process and its implications to lesson design. For instance, with this knowledge, teachers should set task goals, but at the same time provide the time, space and appropriate support for students to be able to exercise their freedom and creativity on how to achieve the goal. In doing so, it will promote the development of interest in learners, enabling them to productively engage with the learning task. This finding should also bring some comfort to teachers and policymakers in that interest can be triggered in a wide range of contexts and situations, such as through challenging tasks, group work and discussion, hands-on activities and even spontaneous activity. It is also of interest to note that Tyler had his interest triggered by "personal relevance" almost all the sessions, but James and Ethan experienced this trigger only during lesson 7, when the teacher was going through revision. The authors postulates that this could be because Tyler has a higher aptitude and knowledge regarding STEM subjects as compared to James and Ethan, and is therefore able to formulate links between prior learning as well as personal interests outside of school.

However, together with this finding, it also highlights the complexity of the triggering of interest and its development, in that simply including a potential trigger into a learning task or environment does not guarantee the triggering of interest. From a practitioner's perspective, it is therefore recommended that teachers craft lesson tasks or activities using various mediums and with varying levels of student engagement required. This will expose students to a wider range of potential triggers, of which one (or a few) may "catch" students' interest. The varied format of lesson delivery will also provide students with something novel each lesson, whereby their interest might be triggered just because of the various ways the lesson is delivered.

Findings from this study also supports previous research highlighting the importance of regular and sustained contact with the content of interest in order for interest to develop (Renninger & Hidi, 2016). Over the course of the 10-week lessons, Tyler was observed to experience a deepening of his interest in STEM and programming, as he could be seen to progress through the stages of the Four

Phase Model of Interest. This was probably due to Tyler not just being regularly exposed to the content weekly, but also through the constant triggering of his interest through the various triggers across the lessons. This study also concurs with Renninger and Hidi's (2020) statement that individuals with more developed interest stretch their understanding and make meaningful connections with the content of interest. Tyler was observed to have his interest triggered whenever he had the opportunity to tinker and extend his learning over and above what was being taught in class. This further highlights the importance of frequently offering students meaningful engagement with the lesson content, to facilitate them making connections from theory into their daily lives. Additionally, these results also show that there are individual differences in the level of cognitive curiosity in a given subject area between every single learner, further emphasising the complexity and layers underlying interest development.

One theoretical and practical contribution of this study is the proof of using EDA as an indicator of triggered interest. In particular, EDA peaks recorded are able to highlight possible instances when an individual's interest is triggered. Such data provides more visual indications, based on physiological responses, on when specific tasks or experiences triggered interest. Even though observational data is able to provide detailed insights on the behavioural responses to various environmental triggers of interest, there may be certain affective or cognitive cues which may be difficult to detect solely based on visual observation. This is evidenced in that even though Tyler reported that he had a low interest in STEM, his EDA responses captured numerous instances throughout the sessions whereby he had triggered interest. On the other hand, James, who reported high interest, had lesser EDA peaks recorded. EDA therefore is able to provide a meaningful complement to observational data in the pursuit of identifying triggers of interest in students. Even though the EDA is still a relatively novel method to measure triggers of interest, it has potential to provide researchers and practitioners with deeper insights into what types of activity catches learners' interest. This can possibly enable a more data-informed benchmark for the development of curriculum or learning tasks which are able to better capture and sustain students' engagement.

One limitation is that this paper is based off a case study of four students. Even though the amount of observational and physiological data generated from this single case study is extensive, it is reasonable to wonder how these findings may differ if the study was conducted with a different demographic. Furthermore, as the school principal were uncomfortable with students being interviewed, it was not possible for the researcher to obtain deeper insights into students' experiences of interest during specific activities, aside from the STEM Interest Surveys. Another limitation is that the current technological affordances of physiological equipment may have limitations of its own. In the case of David, there was only one EDA peak recorded throughout the 10 weeks, which would highlight that he was not cognitively or emotionally engaged by the activities. This could be due to a range of personal factors, such as David being naturally calmer in nature, or him feeling cold during the class, causing lesser peaks and lower levels of EDA to be recorded. This leads to recommendations for future research. One future research possibility is to study and compare a larger group of students perhaps in a more controlled setting in order to have a more fine-grained study of the specific triggers of interest and which of the triggers may be more universal compared to the rest. This could involve selecting and comparing groups of students according to their levels of interests and individual characteristics to investigate how different forms of teaching and teacher activity can support their interest. This could also involve conducting semi-structured interviews to obtain more in-depth data on students' first-hand experiences of interest. By doing so, it will increase the generalisability of this strand of research. Despite the abovementioned limitations, this study is still a significant study contributing to the advancement and illumination of the complex topic of interest research, particularly with the use of EDA as a potential indicator to make the invisible visible. With further physiological research being conducted on interest development, paired with the constantly advancing technology, it may be possible for researchers and practitioners to have a more objective measure of triggers of interest, which would have potential impacts on policy development and teaching practice in the classrooms.

Data availability statement

The datasets generated during and/or analysed during the current study are not publicly available to ensure the confidentiality of the participants.

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