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Affective, meta and collaborative STEAM learning

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Abstract

The purpose of this research was to identify synergies in affective, meta and collaborative STEAM learning, and the level of professional development structure and collaborative support needed for teachers to achieve these. Three project case studies (KIKS, STEAMTEACH and STEAMCONNECT) are examined to do this. In the KIKS (Kids Inspiring Kids in STEAM) project, student groups were issued a very open-ended challenge: "How would you get your fellow students to love STEAM?" They undertook a series of student-led intensive workshops to deliver prototypes and other teaching materials. The intensive, collaborative problem-solving Hothousing workshops focusing on Expectation shock perception enhancement, were inspired by industry practice. The successful outcomes evidenced affective, meta and collaborative learning and suggested the need for further research to develop an associated teacher professional development framework (STEAMTEACH) and also to develop further the collaborative aspect beyond the students (STEAMCONNECT). The projects together delivered over forty project outcomes judged high quality by teachers, students and researchers alike benefitted from affective, meta and collaborative, inclusive learning on many levels from students to teachers to parents to wider community collaboration including local community, business and academic experts. It was thus found that STEAM education can synergically enhance affective, meta and collaborative learning, and for this to happen, should be supported by a STEAM professional development framework and extended networking between teachers, schools, parents, education and industry experts, and community from all abilities and backgrounds.

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1. Introduction

This study explores the STEAM (Science, Technology, Engineering, Art, Maths) integrated, transdisciplinary education approach to identify opportunities to address affective, meta and collaborative inclusive learning. Three project case studies (KIKS, STEAMTEACH and STEAMCONNECT) are examined to do this.

For affective learning, PISA (2012) states that students have to have the opportunity to develop enjoyment, self-belief and mental strength to work hard, and this should be available to all. Picard et al. (2004) expresses affective learning in easily understood terms such as motivation, emotion, interest, and attention. Paiva, Prada, and Picard (2007) identifies affective learning, in addition to any motivational or enjoyment element per se, as important to cognitive development in particular guiding rational behaviour and collaborative decision making. For both meta-learning (learning about learning) and collaborative learning, STEAM teaching can enhance technology, collaborative, personal learning and thinking skills (Gateway, 2020). There is therefore a clear overlap with our three factors - affective, meta and collaborative learning. It is of course possible that the affective factor can be provided within a single subject e.g. Su (2017) describes falling in love with math, Caistor (2012) similarly with history. However, this study will examine whether combining the multi-disciplines of STEAM offers multiple opportunities to provide affective, meta and collaborative inclusive learning and inclusion in a transdisciplinary way.

The EU project KIKS (Kids Inspiring Kids in STEAM) (Houghton et al., 2019) asked over 400 STEAM-loving students in four countries to help their less enthusiastic or less STEAM-able students "How would you get your classmate to LOVE STEAM?". In doing so, this neatly combines the affective factor (how would you get them to love STEAM?), meta-learning (how would you help them learn?), and collaborative inclusion (how would you engage them?). The STEAMTEACH project explores this further with particular focus on meta-learning via its professional development framework (PDF). STEAMCONNECT focuses on collaborative, inclusive learning bringing together students, teachers, parents, education experts and community partners in network collaborations.

In the following section, we examine potential barriers to STEAM learning for both students and teachers, in particular math/technophobia, single subject preference and STEAM itself. We submit that this is essential to understand the barriers that a STEAM approach has to overcome. The KIKS, STEAMTEACH and STEAMCONNECT projects are then discussed in terms of their contribution to STEAM affective, meta and collaborative learning. In doing so, we are driven by the research questions addressed primarily, but not exclusively, in the respective projects:

What are the synergies in affective, meta and collaborative STEAM learning? (KIKS).

What is the nature and level of structure required in terms of a professional development framework to achieve the synergies in affective, meta and collaborative STEAM learning? (STEAMTEACH).

What is the nature and level of collaborative network support required to achieve the synergies in affective, meta and collaborative STEAM learning? (STEAMCONNECT).

The three case studies are examined by analysing quantitative and qualitative questionnaires and interviews with students, teachers, parents and other collaborators.

2. Barriers

There are potential barriers to STEAM. There are anxiety or phobias related to various components of the STEAM activity which as we shall see below are equally applicable to students and teachers. There is concern related to single subject learning, that it may be diluted by being part of a STEAM or other mixed subject approach. Fundamentally, there is concern with STEAM itself, that it may be more a fashion than empirically evidence based.

2.1. Math and Other Phobias

The Centre for Neuroscience in Education (2021) describes math phobia as "a tension, apprehension, or fear that interferes with math performance". This can be debilitating (Ashcraft, 2002; Richardson & Suinn, 1972). Indeed, Young, Wu, and Menon (2012) report fear in a study of children aged 6 - 12 undertaking addition and subtraction tasks. This negativity can extend to career choice (Chinn, 2009).

To add to the potential burden of learning or teaching STEAM, some students and indeed teachers exhibit technophobia (Khasawneh, 2018). Some have collaboration anxiety in activities such as presenting, team working and answering a question in class (National Institute of Mental Health, 2023). Again, the same may apply to teachers asked to work in teams and also perhaps out of field. Perhaps surprisingly, there exists art anxiety, where some people "exhibit a guarded consciousness that constrains unencumbered artistic exploration" (Baer, 2012). This might be most commonly defensively expressed as "*I can't draw*" or "*I'm useless at art*".

There are therefore a potentially large range of phobias or anxieties that may well be hidden from the STEAM educator which have to be overcome or allowed for. How might STEAM help? Not by using art to sugarcoat math, for example, but perhaps by allowing people to play to their strengths and almost forget their phobias, to reach the point where a student or teacher might say "Wow, I'm surprised I managed that!" as in the Expectation shock phenomenon described later (Houghton et al., 2024).

2.2. Single Subject Learning

The issue addressed here is whether it is better to teach subjects singly or in an integrated way. PISA (2016) scores, taken on face value, highlight the outstanding math performances of Chinese students in China, Singapore and Hong Kong. Wei (2014) writing on "what makes science lessons so good" attributes Chinese highest scores to routine practice, rigid practice, whole class instruction, with high degree of parental involvement. So, it is perhaps tempting to adopt this educational approach. However, further analysis presents a more nuanced picture: For example, the results in Australia are comparable and Jerrim (2015) attributes this to a "hard work ethic and belief in the value of education displayed by Chinese parents and children".

This is not to deny the value of single subject learning but that STEAM transdisciplinary collaborative endeavours may also be of value engaging students, teachers, parents and others working together. This will be explored further, particularly in the section on STEAMCONNECT.

2.3. Possible Issues with STEAM Itself

Toma and García-Carmona (2021) expresses caution concerning STEM. This needs to be addressed if we are to develop a high perception of STEM and STEAM in students, parents, teachers and others. To do this, we adopt a STEAM framework from the STEAMTEACH project which presents a professional development framework for STEAM teachers centred around project-based learning (Diego-Mantecon, Prodromou, Lavicza, Blanco, & Ortiz-Laso, 2021). This features content integration, collaborative, problem centred, inquiry based and design-based learning.

Toma and García-Carmona (2021) states that in spite of the "current vogue for STEAM there is a lack of empirical evidence that the STEM (or STEAM) approach has benefits related to solving real problems or learning with a greater scope". Further, it may present more difficulties in, for example, learning specific skills such as scientific procedures and computer programming, more so than a more formal, single subject approach. He further states that with these unknowns surrounding STEAM, we may produce students who are "uninvolved, uncommitted and uninformed citizens" (Toma & García-Carmona, 2021). How STEAM might address this is an important challenge for the next section.

3. Opportunities

In the following project case studies, the synergies of affective, meta and collaborative learning will be examined.

Toma and Greca (2018) found that an integrated STEM educational approach resulted in students' significantly more favourable attitude towards the subject than students from traditional classrooms suggesting that affective learning takes place.

Picard et al. (2004) in "Affective Learning - a manifesto" make the link between affective learning and meta and cognitive learning. They state that findings in multi disciplines support the affective as important in itself but it also contributes to cognitive development in rational decision-making, collaboration, creativity and more. Unfortunately, Shephard (2008) states that higher education focuses on cognitive skills of knowledge and understanding rather than important affective factors of values, attitudes and behaviours. Yet Ozel, Caglak, and Erdogan (2013) described how affective learning directly influenced high school student science achievements. Thus the affective factor is a vital component with potentially much wider impact than just 'liking' a subject.

Metalearning, or learning to learn, can learn and develop more effectively with others, and must also "embrace the affective, connotative and embodiment, mind, body, emotions/feelings" (Jackson, 2007). PISA and the International Baccalaureate support this: "Educational approaches should feature creative problem-solving challenges including societal factors/needs" (PISA, 2012).

Thus we see a joining of affective, meta and collaborative learning.

4. Kiks, STEAMTEACH and STEAMCONNECT

The following section describes the KIKS project (described more fully in Houghton et al. (2019)), with its focus on affective learning via the use of Hothousing intensive workshops aimed at enhancing Perception of STEAM and STEAM careers, and this approach is taken through to the STEAMTEACH teacher professional development framework and the STEAMCONNECT collaborative learning networks.

4.1. KIKS Hothousing and Expectation Shock

The KIKS project (Kids Inspiring Kids in STEAM) addressed the Affective factor head-on and asked students "How would you get your classmate to LOVE STEAM?". Students competed in small collaborative groups in an intensive, typically three session workshop process called Hothousing referring to the intensive, time-restricted, challenging yet fun nature of the activity, having been originally used to get customers and industry experts working together on new product development (Houghton, Lavicza, Diego-Mantecón, et al., 2022). In the educational context our customers and experts include students, teachers, parents and educational experts. In the case of students, they would develop their ideas in group work, present their ideas and come up with a specific deliverable. This could take the form of a physical prototype or learning package. The activity would take place both in-school and online and be subject to periodic constructive evaluation at the workshop events.

Intrinsically linked to the Hothousing process is the phenomenon of Expectation shock (Houghton et al., 2024) which adds surprise or shock element to Picard et al. (2004) affective learning motivation, emotion, interest, and attention. Also, originally from industry, an Expectation shock is when the customer perceives an unexpectedly high level of service. In education, working in creative, collaborative problem-solving groups over a period of time can create an enduring Expectation Shock. Hothousing can thus be a powerful vehicle for delivering an Expectation Shock. The "shock" is the realisation that the student or teacher can achieve unexpected outcomes, and indeed enjoy the experience with lasting effect.

It is the difference between post Perception of the service versus prior Expectation. So, on a LIKERT five-point scale, a customer might be asked a two-part question:

To what extent did you feel the customer advisor was responsive to you?

- *What did you feel before this event?* (the prior Expectation).
- *What do you feel now? (*the post Perception*).*

If a customer is expecting mediocre service (3) but perceives excellent service (5) there is an Expectation shock of 2, which has been shown to engender customer loyalty.

Similarly, a student may not usually enjoy science (with an Expectation 2) but an unanticipated success (Perception 5) may fire their longterm enthusiasm for the subject. From industry and education, a quantitative shift of >0.7 from Expectation to Perception, accompanied by qualitative expressions of surprise, pleasure and/or indeed shock, indicates an Expectation shock (Houghton et al., 2024).

Similar questions might also directly address the concerns for the excluded uninvolved, uncommitted and uninformed citizens raised by Toma previously, for example:

Uninvolved: "To what extent did you feel involved in the activity?"

- *What did you feel before this activity?* (the prior Expectation).
- *What do you feel now? (*the post Perception*).*

4.2. STEAMTEACH Professional Development Framework

The first stage of the STEAMTEACH project was to establish teacher requirements for a STEAM programme and confirm or contrast them with the literature (Houghton, Lavicza, Rahmadi, et al., 2022). In summary, from a semi-structured six item questionnaire also used for interviews with expert teachers, the expert teachers advised that teachers should work in multidisciplinary groups as they were currently working in subject-based isolation. Project- and problem-based learning were identified as key methodologies. Above all, teachers were time-precious: to reach them we had to be as economic with their time as possible.

Collaborative groups and networks were deemed essential to developing transdisciplinary STEAM projects, without which the solo teacher would not have the skill set required (Thibaut et al., 2018) nor the confidence (Weinhandl, Lavicza, & Houghton, 2020).

From KIKS, we had established that real life collaborative problem-solving learning can support affective learning Lieban (2019) and Weinhandl, Lavicza, Hohenwarter, and Schallert (2021). Hence, we anticipated that the Affective factor would be provided by our STEAMTeach approach.

An important factor was the absence of STEAM in the curriculum, therefore it was felt necessary to initially engage with teachers fully committed to STEAM, to lead the way with those teachers with less or no commitment or indeed experience of STEAM. The strategy was to focus on a core of collaborating teachers who would then extend the activity of others. How this was achieved will be discussed in the evaluation.

Two organisations were chosen: Both were middle schools and were linked directly to a teacher education unit, allowing us access therefore to both professional and pre-service teachers.

In the first school, we worked with a five-person team of professional and - pre-service teachers, one only of whom was a STEAM practitioner by choice, again with no curricular or time obligation to undertake STEAM activities.

By contrast, the second school had been appointed by regional authorities to lead the way in STEAM projects, crucially, with time-allocated during the school timetable explicitly for STEAM activities. Nothing was fixed in stone, and indeed the school was eager to fulfil their commitments with our assistance. This team again, was a team of five with both pro and pre-service teachers.

The two teams stayed together over both phases (STEAMTEACH and STEAMCONNECT) of the project workshops and then further collaborated with each other and to engage further with other teachers and collaborating organisations and above all parents.

The two schools both experienced a 2-hour workshop focussing on the STEAMTEACH approach to project-based learning described earlier accompanied by examples. The participants were each asked to come up with a project idea which was then examined for its project-based learning features plus other dimensions identified previously in the STEAMTEACH teacher requirements phase, most notably Affective learning. Each of the three projects demonstrated the adoption of project-based learning dimensions suggesting that the first workshop was understood and bought into by the participants. This would be further evidenced in the more collaborative second workshop by which time this was a STEAMCONNECT project led by the teachers.

4.3. STEAMCONNECT Collaborative, Inclusive Learning

The STEAMCONNECT project aimed to extend from students and teachers to the wider community involving parents, educational experts, industry partners and others to work together on collaborative real-life problem solving in STEAM. These workshops were teacher-driven with the project team as support/evaluators and continued on from STEAMTEACH.

In Feldkirch, the project was entitled: Let it STEAM, let it STEAM, let it STEAM! (Bekesi, 2023). The teacher team consisted of (variable) typically five teachers, pre-service teachers and local college lecturers. The school student teams were aged 10/11. The project was again observed against the checklist project-based learning framework features plus other dimensions, notably affective identified previously in the STEAMTEACH teacher requirements phase (see Figure 1).

The activity sequence started with paper origami activities to software design to 3-D printing and visiting a local 3D factory as:

Figure 1. Project activity and professional development framework checklist.

In Innsbruck the school worked on three projects:

- STEAM to Mars project - an award-winning project extended in Innsbruck together with the Feldkirch school
- BREAD project - a wide-ranging STEAM project, demonstrable involvement of various teacher disciplines, responding to child centred developments, reflection and assessment.
- Digital air quality - a real problem in the school itself, with a community of experts from health/ construction and 11 Tyrol schools.
- There was a focus on collaboration over the projects: STEAM to Mars between two schools, BREAD with various teacher disciplines across schools, and Digital air quality across 11 schools and with a community of health and industry experts.

Figure 2. Plenary workshop.

Finally, a plenary workshop presentation (Figure 2) in Feldkirch featured the presentation of the STEAM to Mars projects featuring the presence of other teachers, parents and community participants: 90 attendees with 30 parents, families and siblings viewed 12 different MARS projects ranging from religion, food, air quality, energy, soil and more.

5. Results

In the following discussion, it is to be recalled that the KIKS project focused on students. It was a voluntary activity so it may be assumed that both teachers and students were pro-STEAM. For teachers, including those with barriers to STEAM, it may be that more support is required and the challenge is to develop an appropriate learning structure (STEAMTEACH Professional Development Framework) and professional support (STEAMCONNECT Collaborative networks). The projects are described below in relation to this. The three case studies are examined by analysing quantitative and qualitative questionnaires and interviews with students, teachers, parents and other collaborators.

5.1. KIKS

The KIKS evaluation is described in Expectation Shock (Houghton et al., 2024). In summary, it brought together both those students able and positive about STEAM together with those less so, covering a wide variety of schools including special needs, and resulting in enhanced STEAM perception. Evidence for this was both qualitative and quantitative.

Students were asked five STEAM related questions on a Likert five-point scale, asking for their before-after views, for example "*To what extent do you enjoy STEAM?*" Taken from Houghton et al. (2024) there were overall enhancements in before-after views in enjoyment, appreciation of technology, teamwork and collaboration skills with shifts of 0.7 or above. As the enhancements were not statistically significant because of the numbers involved (typically classes of 20 or so students), the combination of qualitative and quantitative data gave an opportunity to further support the findings and also to examine individual responses especially where there were no enhancements. From a qualitative perspective, the suggestion of an Expectation shock could be supported in comments from students relating to affective, meta and collaborative learning, for example expressing surprise and delight at their achievement, project planning and sharing of ideas and tasks: "*I just didn't think I could do that*".

5.2. STEAMTEACH

The two three-hour STEAMTEACH workshops for teachers were evaluated from a perspective of teachers successfully understanding and applying their experience, and also whether it was a successful use of their time.

So, from a teacher understanding of the STEAMTEACH project-based learning, we can summarise against the STEAMTeach Project Development Framework described previously:

Problem-based learning context: Students were faced with a variety of challenges developing from starter activities to technological and societal problem challenges from building water rockets to looking at support requirements for living on Mars, through to considering building a better planet and learning lessons from the old one (Earth).

Inquiry-based learning context: The project involved seeking information in a number of areas, making hypotheses and trying out solutions.

Design-based learning context: The iterative design-based approach was evident in various of the project outcomes.

Students collaborated during the implementation phase: The students worked together to create a wide variety of solutions.

From an overall teacher's perspective of the project development framework, the teachers observed that they had a problem to solve, to create a model of a house and without any further instructions, they had to find their own solutions.

5.3. STEAMCONNECT

Having implemented STEAM lessons in the classroom, teachers were invited to complete a six-item on-line questionnaire. Responses showed that they were keen to get ideas, they really liked interdisciplinary tasks and above all collaborating with other teachers. An interesting contribution to teachers feeling positive about collaboration was expressed that in future workshops, they would be happy about further examples to get more ideas and would like to test them in the group first to feel safe when implementing STEAM.

Taking this idea further, teachers saw a key benefit of the integrated team was to allow teachers to play to their specialism rather than out of field (i.e. having to work alone in a non-specialised area). The benefits of the affective factor are thus with teachers also.

Further *"The encounter made it clear how MINKT (STEAM in AUSTRIAN) can network schools, how projects can mesh, how synergies can be used and how knowledge and experience can be shared. Education can overcome borders, open doors and minds, and create spaces for communication,"* said one class teacher,

The STEAMCONNECT workshops provided both a testbed for local inter- teacher collaboration and also for extending to other teachers, parents and community. The format fundamentally provided a safe opportunity to explore STEAM in a time-effective way. Attendees included parents, families, community experts who were asked to complete an anonymous on-line questionnaire using a Likert 5-scale. Their responses showed they recognise:

"This is a STEAM project, Interdisciplinary projects are motivating, and kids learn more from interdisciplinary projects."

As an example, they felt that it is important that kids can present their findings with an average Likert score of 4.66 out of 5 from 38 subjects (Bekesi, 2023).

Collaboration extended to experts such as teachers and researchers for didactics of mathematics in primary and secondary school and collaborators of the international EU projects from the Johannes Kepler University Linz:

"The substantive networking between the university and our practical schools is very important to us against the background of a research-led theory-practice interlocking. The fact that this networking is increasing in quality through partnerships with other schools is particularly gratifying and a further step in the development towards model and research schools."

6. Discussion

We return to address the research questions in turn, attempting to minimise repetition due to the overlap between questions.

6.1. What Are the Synergies in Affective, Meta and Collaborative STEAM Learning?

The affective component was most directly associated with KIKS in asking students how they would get other students to love STEAM. The affective component was retained in further projects. The affective factor encouraged both enhanced Perception of STEAM subjects and STEAM careers evidenced in student surprise or Expectation shock in being able to accomplish a challenging task, confirming (Toma & Greca, 2018) findings of significantly more favourable attitudes with STEAM and Ozel et al. (2013) significant contribution to scientific achievement.

This affective component encouraged meta-learning as evidenced in comments related to planning and putting ideas together into a coherent project.

Also, it was found, as Lieban (2019) and Weinhandl et al. (2021) stated, that real life, collaborative, project-based learning can be highly motivating. This affective factor of enhanced Perception or Expectation shock appeared in answers to the questions concerning the importance of team working skills, communication and collaboration skills, suggesting therefore both meta and collaborative learning experience. This confirms Picard et al. (2004) and Ashcraft (2002) who claimed that affective learning has benefits in cognition and working together.

6.2. What Is the Nature and Level of Teacher Structure Required in Terms of a Professional Development Framework to Achieve These Synergies?

For experienced/enthusiastic STEAM teachers the Hothousing/Expectation shock intensive collaborative problem-solving workshop process was a successful way to enhance student Perceptions of both STEAM and STEAM careers. Lieban (2019) found that project-based learning within an appropriate structure motivates and gives confidence so teachers were able to support their students moving from a teacher-led workshop format to a student driven one in which their roles were primarily experts on call, alongside industry and other experts. This mirrors the business Hothousing in which the facilitator starts leading the activity then gradually assumes a support role.

However, for those teachers and students less experienced and /or enthusiastic in STEAM the professional development framework provided a structure which, akin to a child using a bike with stabilisers, can be progressively internalised to use naturally in STEAM. For teachers as well it is essential to enhance a teacher's perception of STEAM (Thibaut et al., 2018; Weinhandl et al., 2020) in certain cases an Expectation shock, and this structure provides a safe way of doing that. It also, of course, provides a checklist to encourage explicit consideration of specifics such as inquiry or design-based learning.

6.3. What is the Nature and Level of Collaborative Network Support Required to Achieve These Synergies?

The affective element supported and enhanced Perception of the power of collaboration and meta-learning to engage in collaborative problem solving. Examples of the potential benefit of collaboration have been seen but perhaps we have only touched the surface. The extensive collaboration achieved grew naturally and organically. As observes that science collaboration is growing at an astonishing rate and the potential can be seen here. However future research may contribute to how this might be more systematically developed.

The KIKS project with both Hothousing collaborative problem solving and Expectation shock demonstrated the potential of students working together. In the STEAMTEACH and STEAMCONNECT projects, teachers having workshopped together then implemented projects in the classroom valued the opportunity to exchange ideas, the interdisciplinarity and collaborating with other teachers. In addition to developing professional expertise, working together gave them a safe test bed to explore and develop their ideas and expertise, providing as Thibaut et al. (2018) stated essential teacher perceived value and confidence.

This also allowed teachers to play to their specialism rather than out of field. This extends to other schools and dialogue with business, community and academic experts with two-way expertise exchange.

Last but not least we return to the KIKS project and inclusion, to recall that 30% of schools were special needs yet working with the other 70% undertook the same process and delivered excellent projects. Whereas many students feel uncomfortable in groups (Diego-Mantecon et al., 2021) the KIKS process overcame this with, as Dabell (2018) suggested, inclusion of those students not inclined to work in groups. This too suggests the potential of collaborative, inclusive networking.

7. Conclusion

The centre of our interest is students and how best may we support them in the STEAM learning journey. The KIKS Hothousing experience gave the students an affective learning experience which, together with meta and collaborative learning was found to enhance their Perception of both STEAM and STEAM careers, in many cases to the extent of an Expectation shock. The meta-learning was clearly demonstrated in project outcomes and personal learning and thinking skills were exercised and developed. From teacher perspective evidence for the impact of the professional development framework was seen in both the workshop outputs and the subsequent projects.

Extended collaboration suggests further benefits to students and also very much to teachers who play to their strengths and together provide a variety of expert assistance to their students.

Also, the collaboration of students and teachers overcame the various phobia barriers by allowing them to work in a 'safe', trusted environment. Although, in no way disputing the effectiveness of single subject working, it showed how both teachers and students could overcome these barriers to the transdisciplinary STEAM. The concerns around STEAM as perhaps a watered-down mix of subjects appeared to be overcome as both students and teachers could play to their strengths and also explore less familiar areas, again, in a safe environment.

Finally, it has been demonstrated that STEAM can strongly contribute to affective learning, a professional development framework helps both students and teachers in meta-learning and we have initiated wide collaborative learning networks.

Further research is necessary to provide further insight into the potential of collaborative inclusive networks. Above all, STEAM has the potential to be inclusive to otherwise "uninvolved, uncommitted and uninformed citizens" although more empirical evidence is of course required.

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